TM 5-297

WAR DEPARTMENT TECHNICAL MANUAL

WELL DRILLING

WAR DEPARTMENT • 29 NOVEMBER 1943

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(For explanation of symbols see FM 21–6.)

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CHAPTER 1

INTRODUCTION

1. GENERAL. Whenever possible, water supplies for military operations are obtained from existing surface and ground-water installations. Where these supplies are inadequate or cannot be made potable, engineers develop additional ground-water sources.

2. SCOPE. This manual covers the development of ground-water sources for military use. It includes detailed construction methods for the important types of wells and gives advantages and limitations of each type. TM 5–295 deals with methods of water purification. The occurrence of ground water and location of suitable sites for wells will be covered in TM 5–296 (when published).

3. TYPES OF WELLS. A well is a hole or shaft sunk into the earth to obtain a mineral fluid, such as water, from an underground supply. Wells are classified into types according to method of construction as *dug*, *bored*, *jetted*, *driven*, and *drilled*. Each has certain advantages based on ease of construction, storage, capacity, limitations as to formations it can penetrate, and ease of safeguarding against pollution. The first four types are relatively shallow, generally less than 50 feet deep, and may be constructed with hand tools. Since the water in them is usually raised by suction pumps (shallow-well type) the depth to water must not exceed 20 to 25 feet. Drilled wells, the fifth type, are constructed by portable well-drilling machines, either percussion or rotary. All five types of wells are discussed in this manual. Drilled wells, the most important, are covered in greater detail than the other types.

CHAPTER 2

CONSTRUCTION OF DUG WELLS

4. DESCRIPTION.

a. A dug well is a large-diameter well excavated with hand tools, and lined with brick, stone, steel, wood cribbing, or tile (fig. 1). They are seldom less than 3 feet in diameter, and diameters of 15 or 20 feet may be necessary in formations which yield water slowly. They are usually from 20 to 40 feet deep although they may be shallower in favorable locations.

b. The chief purpose of the dug well is to furnish a relatively large supply of water from a shallow source. Dug wells utilize the water from all of the water-bearing formations which they penetrate. They permit the storing of considerable quantities of water because of their relatively large diameters and the reservoir effect thus produced. The yield from a well increases with the size of the diameter but the increased yield is not proportional to the increased size. Because of the large opening and the large perimeter to be protected against the incursion of surface drainage, dug wells are easily polluted by surface wash, by wind-blown material, and by objects falling into the opening.

c. Dug wells may be constructed with simple hand tools and available local materials provided the—

(1) Water table is close to the ground surface.

(2) Formation permits relatively free movement of water into the excavation.

(3) Formation does not cave in during digging operation.

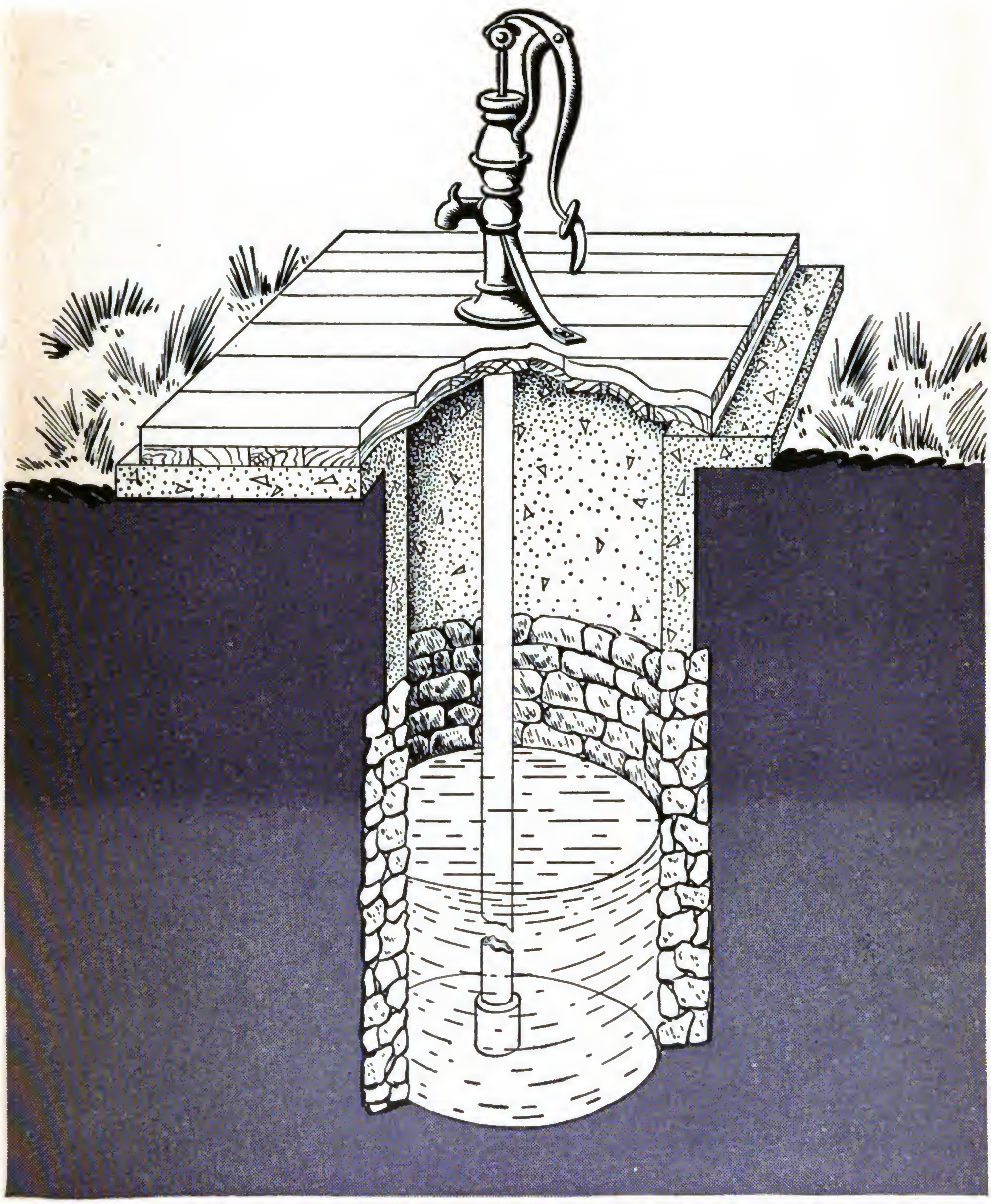


Figure 1. Typical dug well.

5. GENERAL CONSTRUCTION METHODS.

a. Dug wells may be circular in shape or they may be rectangular or square. A circular shape is desirable because it is stronger and is generally easier to construct. Material is excavated with pick and shovel. When

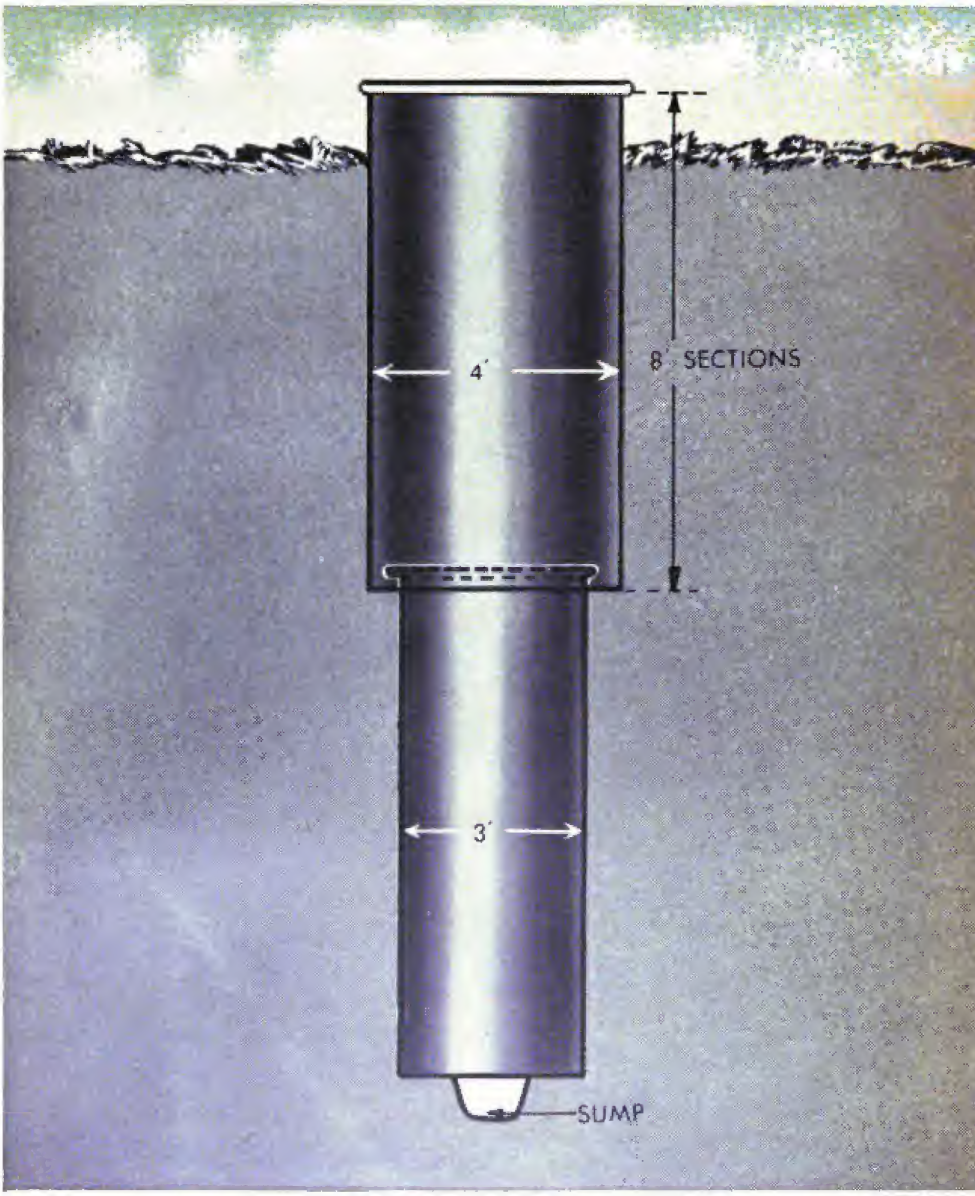


Figure 2. Temporary steel curb in place for digging dug well.

the well becomes so deep that it is not possible to throw the excavated material directly out of the hole or from platforms, a windlass or hoist with a bucket and rope is used to remove it. If the formation in which the well is being dug will stand without support it may not be necessary to

line it until the water table is reached. As soon as the water table is encountered, it is necessary to brace the walls to prevent caving.

b. During the construction of many dug wells of moderate depth, sheet piling is used to brace the sides of the excavation temporarily. Later the forms or sheet piling is removed and the well is lined permanently with brick, stone, or concrete.

c. The permanent lining which is used to seal the sides of a drilled, bored, or driven well is called a "casing." In a dug well, the permanent lining is commonly called a "curb." The curb is placed in the excavation as soon as a depth is reached at which the walls begin to cave. In some formations it is necessary to place the curb as soon as the excavation is started. To keep the curb rigid and to assist in sinking it, iron or timber cutting shoes may be placed under the curb.

d. There are many different types of curbs. The two most common types are the *wood-stave curb* and the *ring curb* (figs. 3 and 4.)

6. WOOD-STAVE CURBS.—Wood-stave curbs may be rectangular, square, or circular in shape and may be constructed with loose staves or with fixed staves.

a. Loose-stave curb. (1)—This curb consists of staves which are held in place by a series of boxlike or circular rigid frames. The staves are placed vertically between the frames and the walls of the excavation. The staves are from 8 to 16 feet long, depending on the depth to water, and are usually 2 or 3 inches thick. They are beveled on the bottom from the inside and placed close enough together to keep sand and gravel from coming through without obstructing the passage of the water any more than necessary. As the excavating proceeds, the staves are driven down one by one with a sledge or a wooden maul. The rigid frames hold the staves in place, and the beveled edge forces out the bottom of the stave as it is driven downward. The rigid frames are driven down occasionally so the lowest frame always will be near the lower end of the staves; otherwise the weight of the material back of the staves forces them inward. The upper ends of the staves are chamfered and then wrapped with several turns of soft steel wire to keep them from splitting while being driven.

(2) When the excavation is about a foot below the water table, it may be necessary to install a pump to keep the water from interfering with the excavating. The pump always must be kept within 15 or 20 feet of the water surface so as not to exceed the suction lift. The pump should have a gate valve at the discharge end for regulating the discharge to keep it from exceeding the flow into the well. A foot valve in the suction pipe also is desirable to eliminate the necessity for priming each time the pump is shut off. Pumps used for this operation should be equipped with a heavy duty screen on the suction pipe to keep coarse gravel and rocks

out of the pump. This screen should have a large area of openings and preferably should be short so the pump will keep the water in the well at a low level. A sump for the pump suction should be kept a foot or two deeper than the floor of the well to keep the water level low. Since sand and gravel which is pumped subject these pumps to severe service, it is preferable to use old pumps for this work.

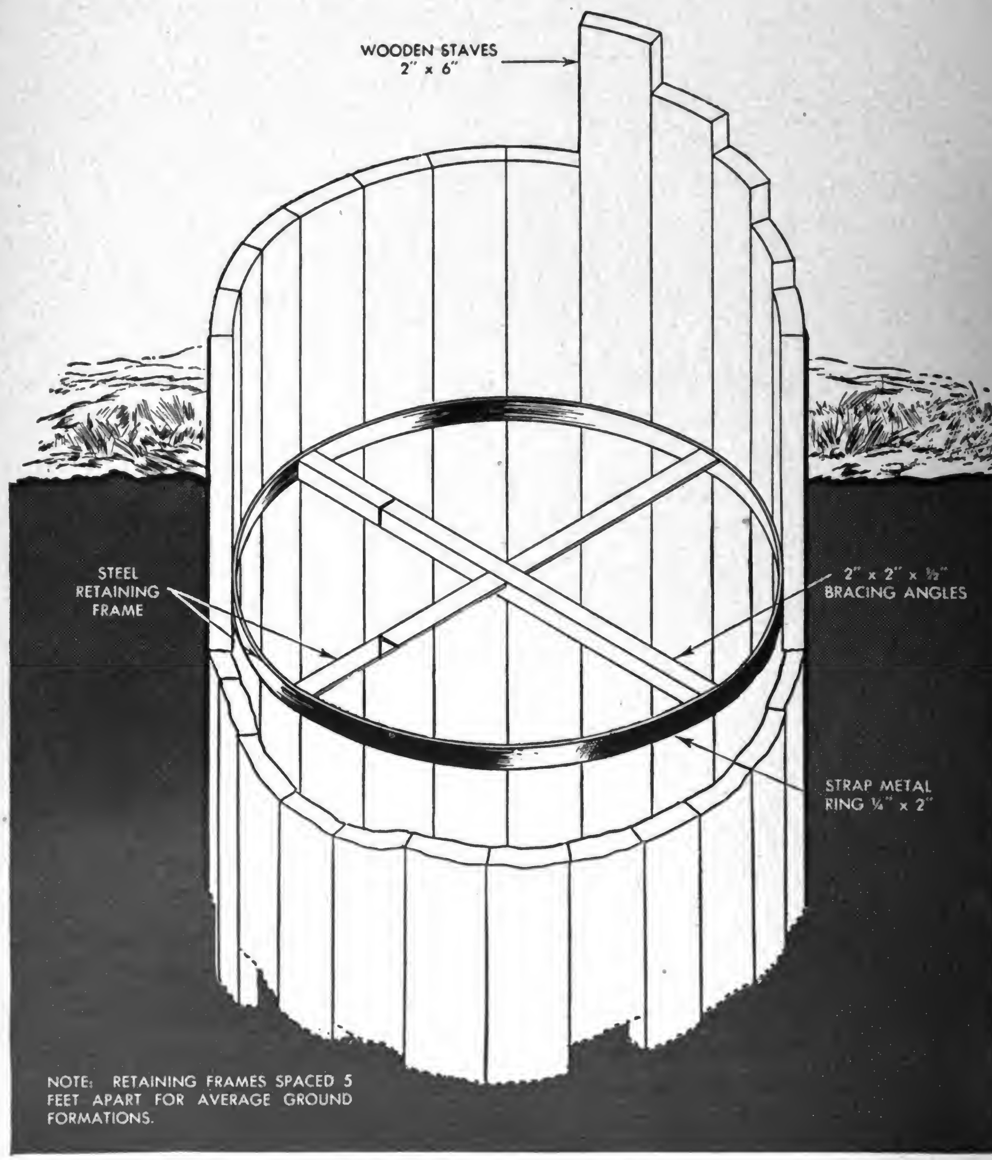


Figure 3. Loose stave well under construction.

(3) When the first set of staves has been driven down as far as possible, a second curb is built inside the first. Each curb added reduces the size of the well. The original diameter of the well at ground surface should be made large enough to allow for the necessary number of reductions.

(4) Considerable difficulty frequently is encountered in sinking wells by the loose-stave method because the pressure on the curb is greater as the depth of the well increases; and when the water is removed from the well, the pressure increases still more. Furthermore, the weight of the material back of the curb and the velocity of the water entering the well under the ends of the staves cause the sand and gravel to wash into the well. If this washing continues, the resulting hole may finally cave in and crush or distort the curb. To keep these cavities filled and thus prevent such a difficulty,

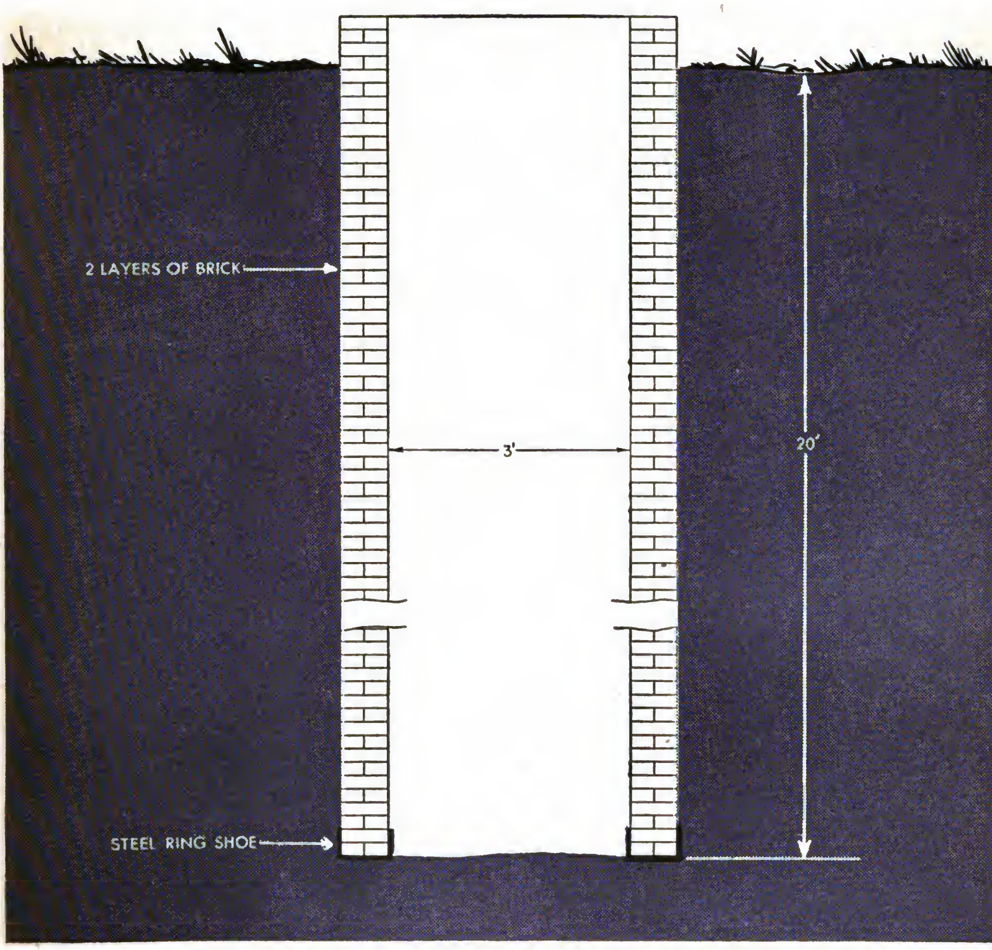


Figure 4. Cross section of dug well with brick curb.

gravel is fed down on the outside of the curb. If this is not done a large area around the well may sink. Sinking is particularly likely if a layer of fine sand is encountered, for it is difficult to keep such sand from running under the bottoms of the staves. Sometimes a foot or more of sand and fine gravel come into the well at one time. This is known as heaving and it usually occurs while the well is being pumped. If it is possible to drive the staves down into the sand a considerable distance ahead of the excava-

tion, they may keep the sand from coming in; otherwise if the well must be dug deeper than planned, a different method of construction must be adopted, or the well may have to be abandoned.

b. Fixed-stave curb. **(1)** This curb consists of a cylindrical tube made of vertical timbers securely attached to a series of rigid frames in the shape of rings. The frames, or rings are built of timber and angle iron cross braces, with a steel rim which is fastened to the staves. The curb is sunk in the same manner as the loose-stave type, except that it is loaded with bricks or concrete blocks to force it down.

(2) When a fixed-stave curb is used, the water is removed from the well by the same methods as previously explained. As the excavation proceeds, gravel is fed around the outside of the curb just as with the loose-stave type. If the well is carried to a solid rock formation, the bottom of the curb should be in contact with the rock at every point; otherwise large quantities of sand and gravel may be sucked into the well when it is pumped. If the curb is stopped in clay, the excavation should be carried a foot or two into the clay so sand cannot come in under the bottom of the curb. If the well is not carried down to a layer of impervious material, it should be backfilled with about 2 feet of coarse gravel to keep the sand from coming in under the curb. If the well is backfilled, a pit should be made for the suction pipe of the pump to keep the pump from sucking air when the well is being drawn to the limit. An oil drum with the head cut out and the sides punched full of holes makes a suitable lining for this pit.

(3) Under favorable conditions the fixed-stave can be sunk as much as 50 feet into the water-bearing formation, but under ordinary conditions 25 feet is the limit if the hole is kept free of water and the digging done by hand. Some of the difficulties in sinking this type of curb may be eliminated if the water is not removed from the well during the excavation. With the water in it, the material is removed from the well with a sand bucket or a clamshell bucket hoist. This method gives much better results because the water in the well reduces the pressure on the curb and also tends to keep the sand from running into the well. If no boulders or layers of clay are encountered, this method is particularly satisfactory.

7. RING-CURB TYPES. This process consists of sinking a brick, concrete block, monolithic-concrete, or large metal casing which acts as a strainer.

a. Monolithic-concrete curbs. These curbs are built in rings 3 or 4 feet high; as the well increases in depth and the curbs sink down, additional rings are added. These rings usually are reinforced, and the individual rings are tied together by the vertical steel left protruding from the top of the ring when it is poured. Inside and outside forms should be used to get a smooth curb that will sink easily, and the portion of the curb in

the water below the limit of draw-down should be perforated. (For a discussion of draw-down per minute see par. 104.) The perforations usually are made by casting short pieces of 1-inch pipe, tin tubes, or pieces of garden hose in the curb. The holes in these tubes are plugged with clay before the tubes are placed in the concrete and are cleaned out after the forms are removed. Several tubes should be placed in each square foot of the curb.

b. Brick and concrete-block curbs. These curbs must be built upon shoes strong enough to support the curb and to resist distortion. Usually the shoe is made of layers of planks similar to the rings used in the wooden curbs but much heavier. Sometimes a metal shoe is used. With the masonry curb, the inside corners of the bricks or blocks are broken off to provide passages for the water. The bricks are laid flat. Only a single row of bricks (4-inch wall) is required for the walls of small wells, but large wells require two rows (8-inch wall) laid end to end and tied together every four or five courses by a row of bricks (bond course) laid side by side.

c. Large metal curbs (fig. 2). These curbs generally are made of used material. The bottom of the curb is strengthened by a steel ring made from a heavy flat bar or angle; and if the curb is not very rigid, additional stiffening rings are added at intervals throughout its length. The curb may be perforated below the limit of draw-down by punching it full of holes from the inside, or by cutting slots with an acetylene torch, or by drilling holes from ⅜ to ½ inch in diameter. The results are best if the perforations are made before the curb is placed in the well. If the curb does not sink readily, it may be loaded on the inside with brick, but if so, an angle iron instead of a flat bar should be used for the stiffening ring at the bottom of the curb to support the courses of brick.

d. General excavation features. Ring-curb wells generally are excavated by hand with spades and shovels, but a sand bucket ot clamshell bucket with a power hoist may be used when no boulders, layers of clay, hardpan, or other consolidated materials are encountered. When a monolithic-concrete curb is being installed, coarse gravel should be placed outside the curb to keep the sand from coming through the perforations, which usually are large in this type of casing. Under favorable conditions brick or concrete-block curb wells can be dug from 15 to 20 feet into the water-bearing material, and even greater depths are possible with monolithic-concrete or large metal curbs.

CHAPTER 3

BORED WELLS

8. GENERAL. Bored wells are constructed with hand or power earth augers. They are used where speed and economy of material are essential and where relatively small quantities of water can be obtained at shallow depths by penetrating unconsolidated formations. An auger can be used only where the formations, though relatively soft, will permit an open hole to be bored to depths ranging from 25 to 60 feet without caving. Formations most suitable for boring methods are glacial till and alluvial valley deposits. In favorable locations, bored wells may be constructed by general engineer troops using organic equipment only.

9. HAND AUGERS.

a. A common type of hand-operated auger is shown in figure 5. It consists of a main shaft or pipe with a wooden handle at the top, and a cylindrical boring device with curved blades at the bottom. The blades may be fixed or they may be adjustable for boring wells of different diameters. The standard issue auger has fixed blades.

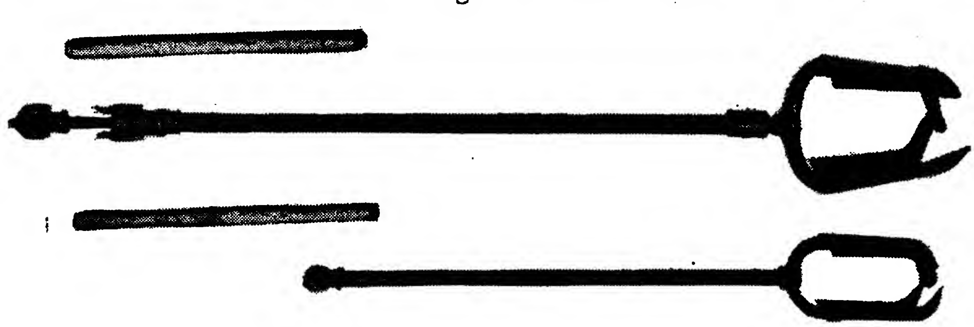


Figure 5. Hand auger.

b. All hand augers are operated similarly. Boring is begun by forcing the blades of the auger into the ground while twisting the handle. Usu-

ally the auger will cut its way into the soil with little downward pressure. When the space between the blades is full of material, the auger is removed from the hole and emptied. This operation is repeated until the desired depth of hole is reached. The hand auger usually is furnished with extensions having couplings for connecting them to the auger pipe. The extensions are added by unscrewing the handle, assembling the extension to the auger pipe with the coupling, and then replacing the handle. When a boulder is encountered, the auger is removed from the hole and the lower cutting section is removed and replaced by a spiral auger or ram's horn (fig. 6). This tool is lowered into the well; when the handle is turned, the wire usually will twist around the boulder so that it can be removed. The cutting section then is replaced and boring continued.

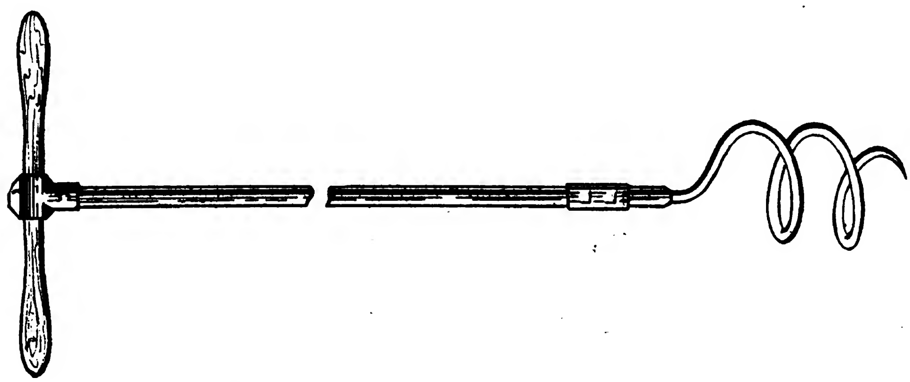


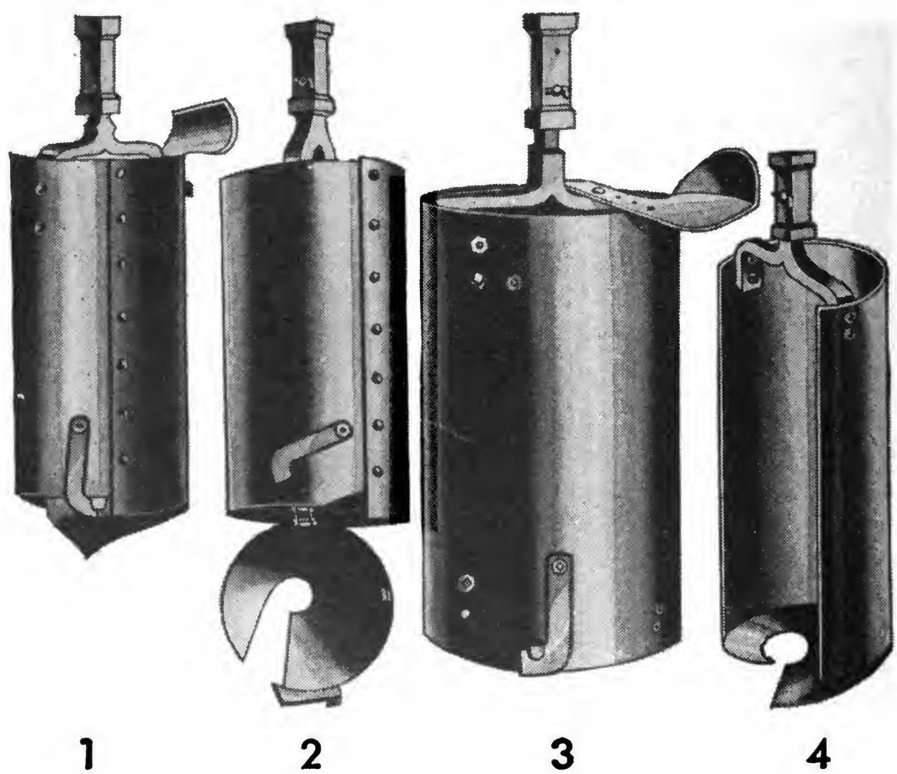
Figure 6. Spiral auger or ram's horn.

c. Wells less than 40 feet deep ordinarily do not require boring equipment other than the auger. When greater depth is desired, it is necessary to use a light tripod with a pulley at the top, or a raised platform, so the longer auger rod can be inserted and removed from the hole without damage and without unscrewing all sections of pipe at each withdrawal.

10. CASING. If loose sand and gravel are encountered, as frequently occurs when boring in alluvial formations, progress below the water table sometimes is impossible. The best expedient in such a case is to lower casing to the bottom of the hole and continue boring inside it to the desired depth. If this method fails, frequently the hole can be carried deeper by using a bailer or sand pump to remove the sand, while adding weight to the top of the casing to force it down as the material is removed from the hole.

11. POWER AUGERS. Larger, power-driven earth augers are used to bore wells from 8 to 32 inches in diameter. Boring is done by augers of two general types, the cylindrical-bucket type, with cutting blades

at the bottom such as those illustrated in figure 7, and the open-blade type such as the truck-mounted, gasoline-powered auger. All these augers are rotated, raised, and lowered by power-driven mechanisms. The turning force is transmitted to the auger through jointed square or polygonal stems. Material is removed from the cylindrical-bucket type auger by opening the hinged side or bottom. The loaded open-blade type auger is withdrawn from the hole and dumped by a quick whirl of the rotating mechanism, which throws the material away from the hole by centrifugal force. The standard power auger issued to engineer troops is limited to a depth of about 10 feet. Therefore it is satisfactory for well-drilling in favorable locations only.



1. *Closed auger with nonadjustable reamer.*
2. *Auger with bottom open for dumping.*
3. *Auger with adjustable reamer.*
4. *Half-round auger.*

Figure 7. Well augers.

CHAPTER 4

JETTING METHOD OF WELL CONSTRUCTION

12. EQUIPMENT. The equipment for the jetting method consists of an inner tube which is a drilling or jetting tube; and an outer tube which is well-casing. A power-driven pump with suitable hose attachments supplies continuous water pressure during drilling. One type of rig uses a block and tackle or a tripod for controlling the tools and casing. Larger rigs have a mast and hoisting block, and use engine power for handling the casing, drive weight, and pump. Figure 8 shows diagrams of a jetting rig, and figure 9 shows various types of jetting points.

13. GENERAL DESCRIPTION.

a. Through a pipe of relatively small diameter, water is led into the well and forced downward through the drill bit against the bottom of the whole. The stream loosens the material, the finer portion of which is carried upward and out of the hole by the ascending water, as in the hydraulic rotary method described in chapter 7. During drilling, the jet pipe is turned slowly to insure a straight hole. Casing usually is sunk as fast as drilling proceeds. In the softer materials, by using a paddy or expansion drill (fig. 9) a hole may be made somewhat larger than the casing, which then may be lowered a considerable distance by its own weight. Ordinarily, however, a drive weight is needed to force it down. As a rule one size casing is employed for the entire depth of the well. Usually it is difficult to drive a single string of casing beyond 500 or 600 feet by this method. If the well is sunk much deeper, an additional string of smaller size must be used. In fine-textured material the hole often may be jetted to the full depth and the casing inserted afterward. The wall of the hole becomes puddled by the muddy water so it will stand alone, like the wall of a well drilled by the hydraulic rotary method.

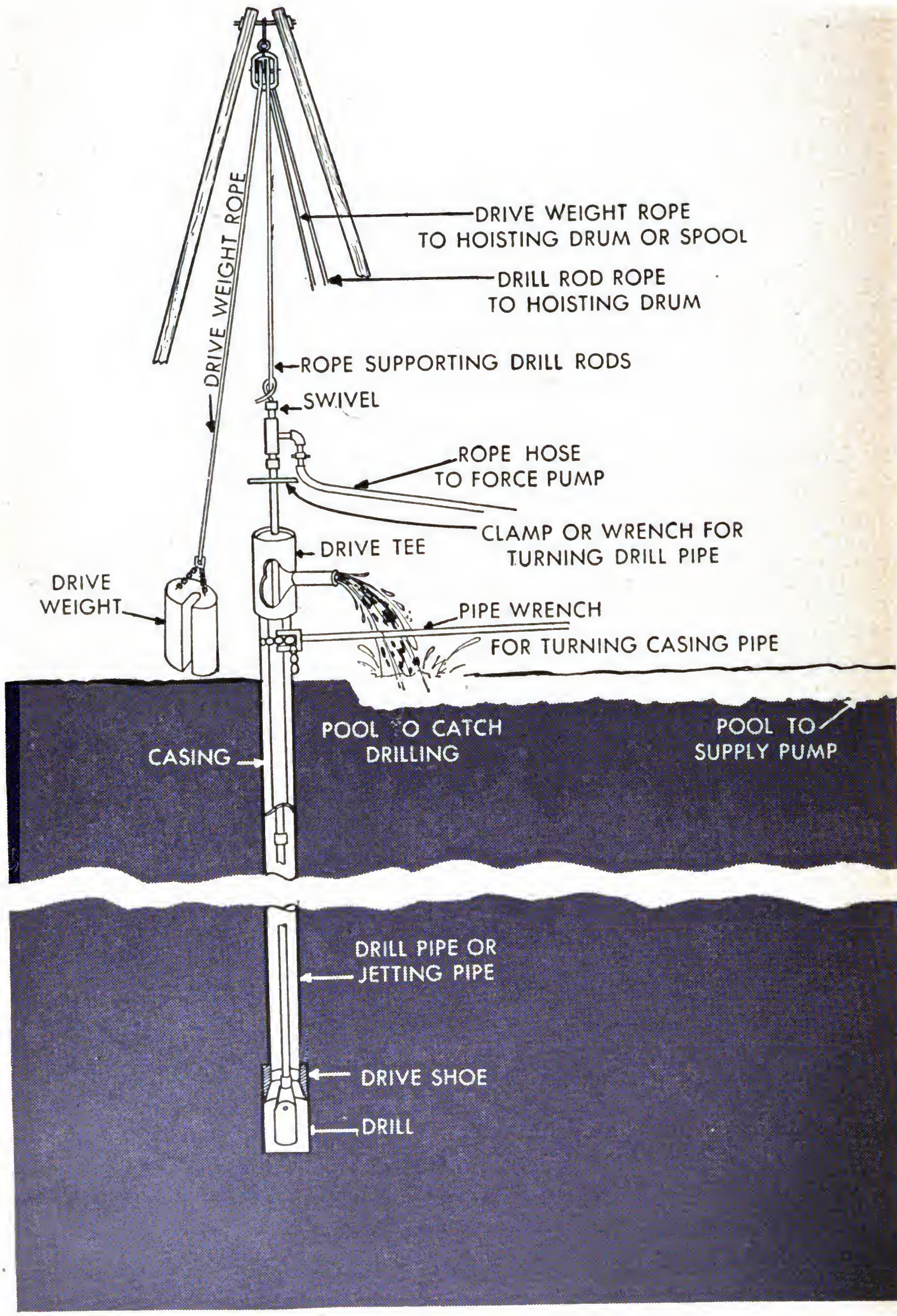


Figure 8. Simple jetting rig.

b. Hard layers are penetrated with a light rig by using a drill bit on the drill pipe and raising and dropping the pipe to strike blows, as in the percussion method covered in chapter 8. A check valve usually is inserted in the drill pipe near its bottom to prevent loose material from clogging the pipe when jetting is stopped. With a heavier rig, equipped with mast and hoisting block, a cable and small drill are used for penetrating locally hardened layers that do not yield readily to the water jet.

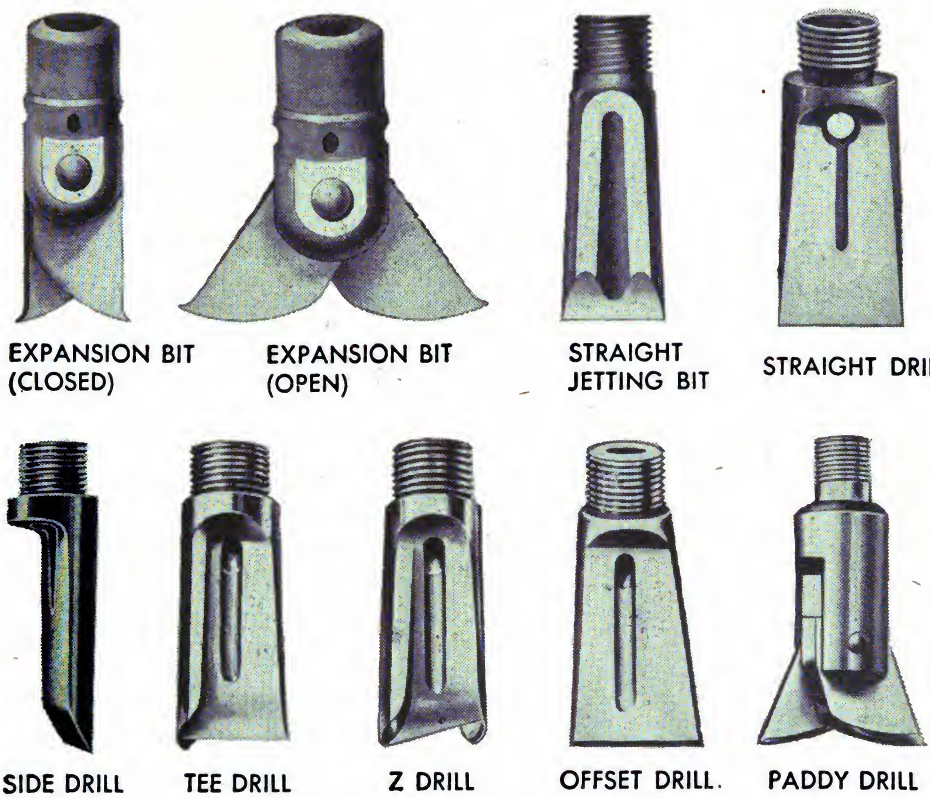


Figure 9. Equipment for jetting wells.

14. SINKING SHALLOW WELLS BY HYDRAULIC METHODS.

a. The jetting method is particularly successful where water is found in sand at shallow depths. It is exceedingly simple, dependable, can be done by hand, and its success does not depend upon bulky drilling rigs which are difficult to transport. Futhermore, it sinks wells rapidly, so it is possible to put into service pumps of fairly large capacity within 10 minutes after starting operations.

b. In this method, a casing is washed vertically into the ground so that it extends below the water table. The water used in the work is carried by a tank truck. A pump of fairly high pressure delivers the water to the end of the casing through a washing nozzle, and a hole is thereby washed into the ground ahead of the casing. After the casing

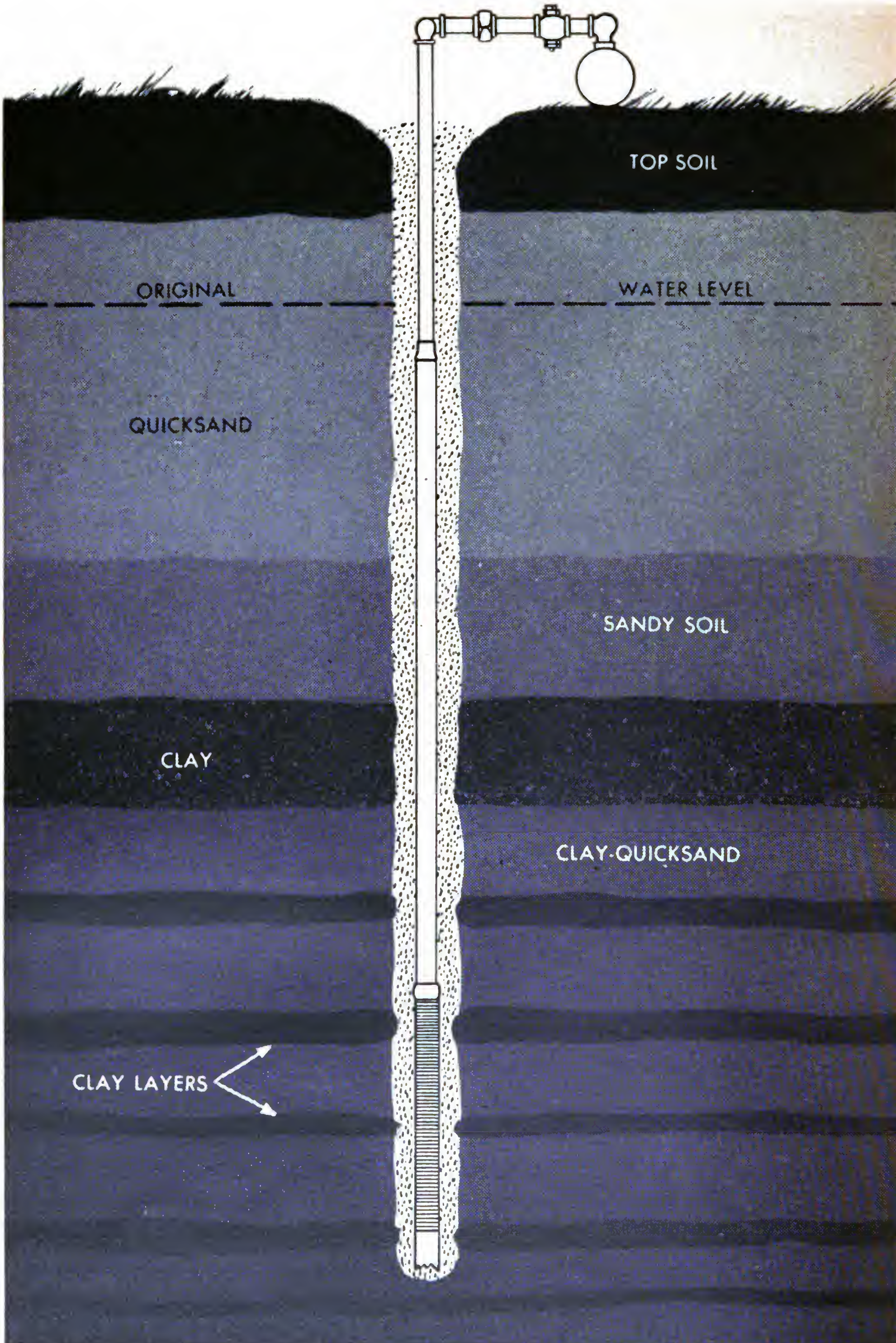


Figure 10. Cross section of jetted well showing self-jetting well point in place.

reaches the required depth the well pipe, with the screen attached, is lowered into it; the outer casing is then pulled, leaving the well screen in the ground below the water table in position for pumping (fig. 10).

c. The work of establishing a well by this method, and pumping from it, has six different steps:

(1) Washing-in of casing. (a) This step sinks the well hole into which the screen finally is dropped. The intake hose leading from the pump is attached to the water tank. A discharge hose leads from the pump to the jet pipe which is placed inside the casing. The casing and the jet pipe with washing nozzle attached then are held in a vertical position with the lower end of the casing resting on the ground. The pump is started, and water drawn from the tank discharges under pressure from the tip of the washing nozzle and washes a hole into which the casing sinks. While sinking, the casing is rotated to prevent "freezing" because of soil friction on the outside. For this a special wrench is required which may be handled by one or two men; the washing nozzle is operated by a third man. The material beneath the casing continues to wash away, making a hole into which the casing sinks as fast as the displaced material is carried away by the water. The jet's cutting and washing actions are controlled by alternately raising and lowering the washing nozzle. In normal formation the tip of the nozzle should be even with the bottom of the casing. The process is continued until the casing has been washed in to the required depth. The washing process is rapid, especially in sand. In loose material, 20-foot casings may be sunk in approximately 3 minutes. Approximately twice as long is required to sink the casing through clays and hardpans. Until it reaches the water table, no advantage is gained by forcing down the casing faster than the water jet can make a cavity below it, The water jet is the cutting tool, and the casing simply takes up space created by its action.

(b) Displaced sand is disposed of in two ways, and the change from one to the other occurs after the tip of the casing reaches the water table. At first the material drops around the casing at the ground surface, forming a cone as the washing continues. After the tip of the casing penetrates the water table, the discharge at the ground line ceases, the water rises in the casing, and the sediment thereafter discharges from its top. After the water table is penetrated, considerable advantage is gained by crowding the casing slightly. This forces the lower rim of the casing tightly against unwashed soil, resulting in reduced absorption of the water from the nozzle and the return of the maximum amount of water to the top of the casing, bearing the sediment with it.

(c) The quantities of water required to sink casings vary with the types of sediment met and with the length of the casing. Sandy sediment

requires most water. Fourteen-foot casings, 4 inches in diameter, may be sunk to full depth in sand with 75 to 80 gallons of water, in 2 minutes; 18- to 20-foot casings, 4 inches in diameter, can be sunk in sand with 120 to 150 gallons. High pressures are not necessary; 40 pounds per square inch is adequate for work in sandy sediments.

(d) Clays and hardpans have requirements entirely different than sand. They are tenacious and are not readily displaced except by a sharp cutting stream delivered at high pressure. Large fragments of material are not washed free at any one time, so large quantities of water are not required. Volumes of 20 gallons per minute are adequate, at pressures as high as 200 pounds, which can be obtained from small nozzles. Usually it takes at least twice as long to sink casings in clay as in sand. The same is true in hardpan, but hardpan formations often are thin, and casings sink rapidly after the cemented layer has been pierced.

(2) Clearing casing. Washing in the casing makes and maintains the hole into which the well screen is lowered. In coarse sands and gravels no sediment of any kind remains inside the casing; its entire length is clear, ready to receive the well screen. A foot or two of the lower end of the casing, however, frequently fills with sediment. The casing is cleared by raising and lowering the washing nozzle and by avoiding further violent disturbance of unwashed sand below the open end of the casing, until the water flowing over the top is clear and free from sand.

(3) Placing well screen and pipe. The well screen and pipe are placed in position by lowering them into the casing, which acts as a sheath. The well screen should rest in the solid, undisturbed material at the bottom of the casing. The well pipe should not stand more than 18 inches above the surface of the ground. This insures the lowest possible suction lift.

(4) Pulling casing. The well screen is exposed to the water-bearing stratum by pulling the casing, leaving the screen and pipe in the ground. Casings are easily pulled with a chain and pry, although a specially built casing jack is more satisfactory. Unless some unusual difficulty is encountered, a casing can be pulled in 2 or 3 minutes.

(5) Coupling pump to well. Removing the casing leaves the well screen in position and ready for pumping. The well may be used for pumping simply by coupling the intake hose leading to the pump to the exposed end of the well pipe. The intake hose should have female couplings on both ends to simplify coupling it to the pipe. All joints and gasket faces must be in good condition and absolutely airtight.

(6) Pumping from well. Coupling the intake hose with the exposed well pipe completes the well, which will yield water immediately if the pump is in good condition and the screen has been properly placed below

the water table. When water is obtained it is good practice to direct the stream onto the well pipe at the ground level, to wash a soil pack around it. The well is then ready for continuous pumping. At first, considerable quantities of fine sand are discharged from the nozzle, after which a pack of coarse material is formed around the well screen and the discharged water is clear.

15. EQUIPMENT REQUIRED FOR JETTING WELLS.

a. Casing. The lower rim of the casing must be equipped with teeth cut from the metal itself. Four teeth about 1 inch deep are ample. To tooth casings, the outlines of the teeth are marked on the outside of the casing with a pattern. The gullet of each tooth is drilled with a power drill, and the straight sides of each tooth are cut with a hacksaw to meet the *circumference* of the drilled hole. Rounded gullets are desirable to let the teeth clear themselves readily of gravel and other obstructions. When a casing is being washed in, it is rotated by wrenches, and the teeth develop a sawing and tearing action which aids greatly in cutting through layers of compact material and gravel. When a toothed casing is used the displacement of sediment, therefore, does not depend entirely upon the abrasive action of the washing stream.

b. Overflow funnel. Previous mention has been made of the return flood of water and soil overflowing the casing after the lower rim has reached the water table. Sometimes this occurs when the casing is still sufficiently high in the air for the flood to drench the workmen who are handling the wrenches. It may be prevented by a simple attachment to the casing, called an "overflow funnel." The funnel is a short length of tubing identical with the casing. It has a sleeve which can be slipped inside the casing so the funnel rests on the upper rim of the casing and acts as an extension to it. An outlet at the side of the funnel drains away the water and sediment before it rises high enough to overflow. A short hose carries the water to one side.

c. Casing wrench. A special wrench is desirable for imparting to the casing the oscillating action which prevents it from "freezing" while it is being sunk. The wrench must grip the casing firmly regardless of the direction of rotation. Furthermore, it must release its grip instantly and take hold again when the wrench is slipped higher up. A satisfactory wrench with a gripping cam is cylindrical in shape and is slipped over the end of the casing. A lever arm, ending in the cam, engages the casing; the wrench is loosened and moved up the casing by moving the lever. Two handles for the wrench permit men to work on opposite sides of the casing. Wrenches of this kind are not on the market, but can be made in any first-class blacksmith shop. A standard pipe-vise jaw prevents the casing

from slipping. The jaw projects through a slot in the collar of the wrench; it is adjustable to several sizes of casing.

d. Washing nozzle. The washing nozzle normally is the end of a standard 1/2- or 3/4-inch pipe, the upper end mounted with a 1-inch Y to which the hose leading from the power pump is attached. The lower end of the pipe has a coupling to accommodate tips of several sizes. The length of the pipe is important; it must equal the length of the casing with which it is being used but will not give satisfactory results if it projects more than 2 inches beyond the lower end of the casing. The tip used with the nozzle depends on the formation. Since coarse, loose sands are easily displaced, and relatively large fragments of material must be carried away by the water flood, low pressures and fairly large volumes of water are required to sink the casing. Large openings, therefore, should be used to sink casings in sandy soils; 1/2-inch nozzles are satisfactory. In clay and hardpan the situation is reversed. Such formations resist rapid displacement by the washing stream. Consequently, high pressures are required. Pressures as high as 200 pounds, or up to the safety limit of the hose, should be developed in such instances, and nozzles having openings of 5/16 or 3/8 inch are most satisfactory.

e. Nozzle hoist. When casings are handled entirely by hand the nozzle hoist aids in raising and lowering the washing nozzle while the casing is still high in the air. The hoist is a bar of wood fitted with a hook and a clamp so it may be hung on top of the casing. A pulley is attached to the top. The nozzle may be controlled by a rope attached to the Y-bend and run through the pulley to the ground. After the nozzle is within reach of an operator on the ground the hoist may be dispensed with. When a tank truck is equipped with a ladder derrick a nozzle hoist is not required; the nozzle operator can follow the casing to the ground and control the nozzle by hand at all times.

f. Nozzle stop. The nozzle stop is a small clamp that prevents the tip of the washing nozzle from protruding beyond the lower rim of the casing while the latter is being washed into the ground. It eliminates the necessity of adopting standard lengths of casings and washing nozzles, and through its use one nozzle can be used with any length of casing, up to the full length of the washing nozzle itself. Unless some such device is used, the washing nozzle must be cut exactly to the same length as the casing being sunk.

g. Jetting bit. The jetting bit, a combination of chisel and high pressure washing tip, is indispensable in clay soils and hardpan. It is attached to the end of the jetting pipe. When used in compact sediments, three types of cutting action develop: First, the toothed casing cuts a core which rises inside the casing; second, the high-pressure stream of water

helps to disintegrate the core; and third, the chisel tip thoroughly chips up the large fragments by direct cutting. Clay can be penetrated by use of the jetting pipe alone, but hardpan requires the jetting bit.

16. OVERCOMING OBSTACLES.

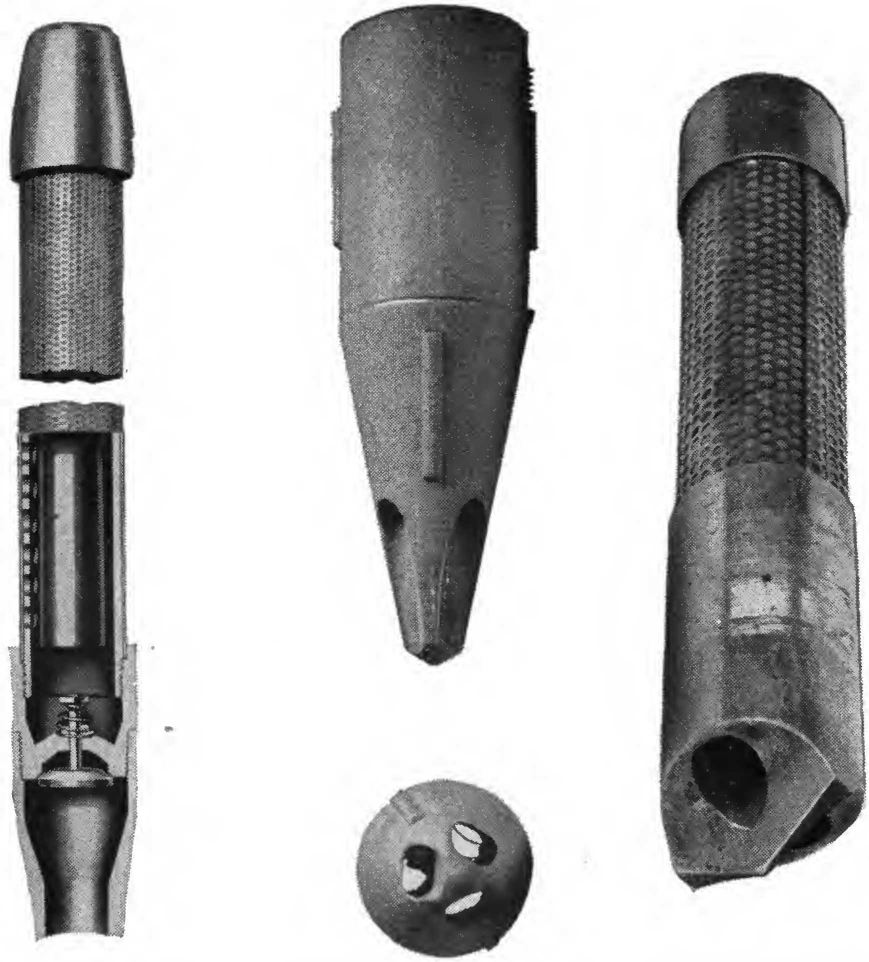
a. Certain underground conditions present difficulties to this method of well construction. Rock formations and boulders are barriers that cannot be overcome by hydraulic methods. Formations of clay and hardpan are other types of materials that ordinarily present problems. However, in such formations if the water table is within about 20 feet of the surface, wells can be successfully established by the use of toothed casings and the jetting bit. Gravel is difficult to penetrate with smooth-ended casings, but toothed casings penetrate it without any trouble; the teeth saw their way free, and gravel up to the size of small marbles can be cleared easily from the casing.

b. Where underground conditions seem uncertain and obstacles may be present, time and effort can be saved by sounding to determine the nature of the underground formations. Sounding is done by rigging a washing nozzle equal in length to the casing to be used and washing it vertically into the ground at the chosen spot. As it descends it explores the material and "feels out" obstacles which might hinder a casing. Sounding is good practice where the thickness of clay layers is not known, or where hardpan or boulders may be met. When test holes reach obstacles, suitable well sites may be found by moving a short distance away and sounding again. Clay layers generally vary in thickness, and hardpan formations may not be continuous; open areas and thin spots may occur through which a casing can easily pass. Large boulders sometimes may be avoided simply by sinking the nozzle a few feet to one side.

17. WELLS WITH SELF-JETTING WELL POINTS.

a. When such points are used it is not necessary to wash down a casing and then drop in the well screen. The equipment necessary for the installation of wells of this type includes a self-jetting well point, a well pipe, a small swivel to permit turning the pipe to facilitate the jetting, a pressure hose, a suitable jetting pump, and a source of water. Figure 11 shows three types of self-jetting points of which two have screen attached, and a cross section of a typical jetted well with pipe and screen in place. The self-jetting well point is a separate unit screwed to the pipe by a suitable connection. It is a tube of brass mesh protected by an outer screen of heavy, perforated brass. The lower end terminates in a jetting nozzle which is easily replaced if damaged.

The nozzle or point contains a ball type or spring-controlled check valve which opens when water is forced through it at high pressure during



① *Open-end jet point.* ② *Tapering-point jet head.* ③ *Bit-type jet point.*

Figure 11. Self-jetting well points.

the jetting operation. It closes after the point has been sunk and the well connected to the suction pump. The jetting pump usually is of the single- or multiple-stage centrifugal type, the number of stages depending upon the pressure required.

b. No preliminary boring operations are required before sinking the well points. The riser pipe and well point unit are coupled to the discharge hose from a jetting pump. The well point assembly then is up-ended and placed in position by the jetting crew. Usually three men are sufficient for the entire operation. The pump is started, and the jet of water displacing the ball valve (fig. 11①) issues from the nozzle at the bottom of the well point. The jet breaks up the soil, washes the displaced material to the surface, and allows the well point to sink to the desired depth. (fig. 10). With coarse sand a pressure at the nozzle of 40 pounds per square

inch is sufficient, but 100 or 150 pounds may be required with gravel or clay. For low pressures the discharge side of the suction pump may be used, but for higher pressures a separate pump, or two pumps running in series, may be necessary. A large volume of water under high pressure is recommended, not merely to install the well point but also to break up the surrounding material and wash out the fine sediment, thus providing space around the screen for gravel treatment, if desired. After the well point has been sunk to the desired depth, the hose is removed and the riser pipe is coupled to the suction side of the pump for development. These wells can also be developed with an ordinary pitcher pump, as described in the section on driven wells. See chapter 9 for methods of well development.

CHAPTER 5

DRIVEN WELLS

18. GENERAL DESCRIPTION.

a. A driven well is constructed by driving a pointed screen, called a "drive point", and attached pipe directly into a water-bearing formation. The finished well consists of a series of lengths of pipe fitted at the upper end with a pump and at the lower end with a sand screen through which the water is admitted. The drive point consists of a perforated pipe with a mild steel point at its lower end to break through pebbles or thin layers of hard material (fig. 20). After this section has been driven down, succeeding sections are screwed into place and driven like the first, until the water-bearing stratum is reached or further progress is prevented by increasing resistance. The pump then is attached, and after the well has been developed, it is ready for use (fig. 12).

b. The chief use for driven wells in military operations is for emergency operations where the water table is near the surface. The equipment is portable, simple to install, and the process is economical in time and labor.

c. Drive point wells usually range in diameter from 1 1/4 to 2 inches, but larger sizes up to 4 inches also are made. The larger sizes, although of greater weight and more difficult to drive, have the advantage that deep-well pumps can be used when necessary. The smaller sizes, because of their lesser weight and greater portability, are valuable for determining the depth of water-bearing formations and for testing yields at shallow depths.

d. The depth of the well is limited by the formations encountered and by the type of pump available. For small wells the ground water level must be within 25 feet of the surface because suction pumps gen-

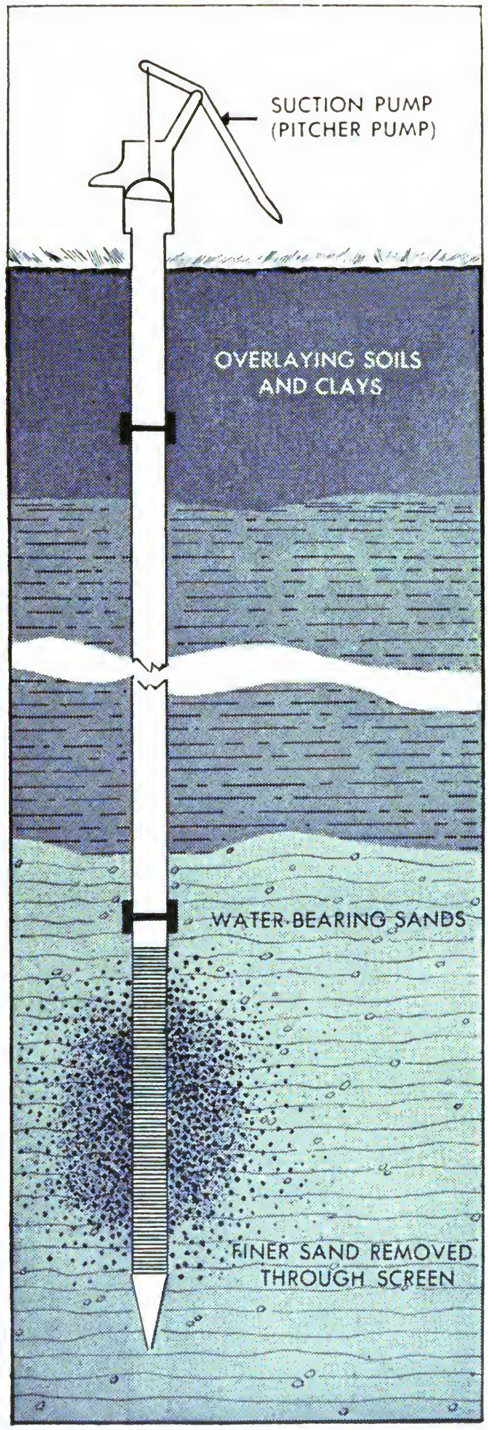


Figure 12. Finished drive-point well.

erally are used. If small self-priming centrifugal pumps are used, the lift must be less than 25 feet. If 2-inch or larger pipes are used, it is possible to lift water from a greater depth by installing a Eureka cylinder or similar type pump near the water level.

19. LIMITATIONS.

a. The following conditions are necessary for successful driven wells:

(1) The formation into which the point is being driven must not be too hard and compact.

(2) The distance to ground water must not exceed the lift of the pumps available.

(3) The water-bearing formations must have moderately high permeability to provide adequate yields in small-diameter wells.

(4) The wells must be developed properly to obtain sufficient water.

b. Chief disadvantages against general use of driven wells are:

(1) Construction is laborious and slow when tightly compacted soils are encountered.

(2) Driving is destructive to well equipment; points frequently are stripped of mesh; pipe is bent and broken.

(3) Couplings frequently are belled by the force of the hammer blows; such joints always leak air and either render the well useless or seriously impair the yield of water.

(4) Yields are small from any one well point; as many as five points connected in series may be required to operate a power pump to capacity.

20. LOCATIONS. For detailed information on the location of sites for driven wells, refer to TM 5–296 (when published). Driven wells are located only after a field study of the local geology and topography has been made, since few formations other than unconsolidated sediments of relatively recent geologic ages can be pierced by drive points. Suitable locations for driven wells are as follows:

Location	*Common sediment types*
River valleys.	Sands, silts, clays.
Beaches and coastal dune areas.	Sands, gravels, silts, clays.
Deltas of large rivers.	Sands, gravels, silts.
Sandy glacial deposits.	Sand, gravel, silts.

21. CONSTRUCTION METHODS.

a. In civilian practice, drive points normally are driven with equipment which is too heavy and bulky for military use. The methods of construction covered in this paragraph deal with items which are relatively light and portable.

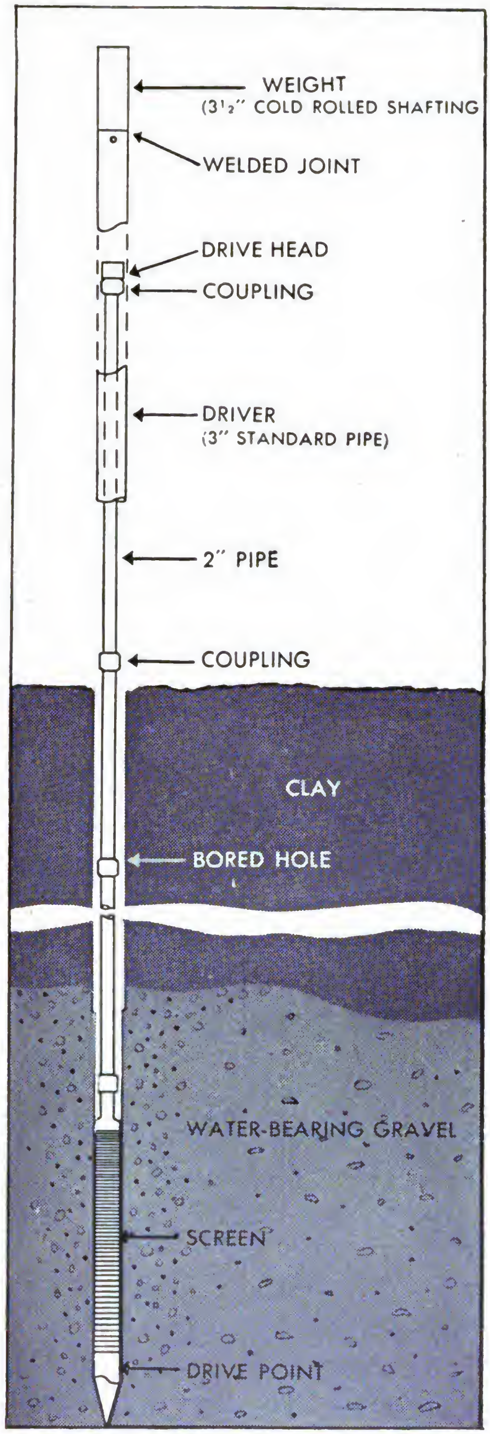


Figure 13. Driving a well point with simple driver.

b. Driven wells generally are started with a hand auger slightly larger than the diameter of the pipe to be used. The auger should be used until boring becomes difficult. In some formations, such as clay, boring with an auger is much faster than driving. In average formations two men can bore a hole with a hand auger to a depth of 25 feet in 1 hour.

c. There are many ways to drive the pipe into the ground. The most common simple ways are with—

(1) A hand-operated driver similar to the type used for driving fence posts. This operation, illustrated in figure 13, requires no equipment except the driver itself.

(2) A steel bar attached to a rope. The bar falls freely inside the pipe at the base of the drive point as shown in figure 15. This is one of the easiest and safest methods of driving, because it does not weaken the pipe.

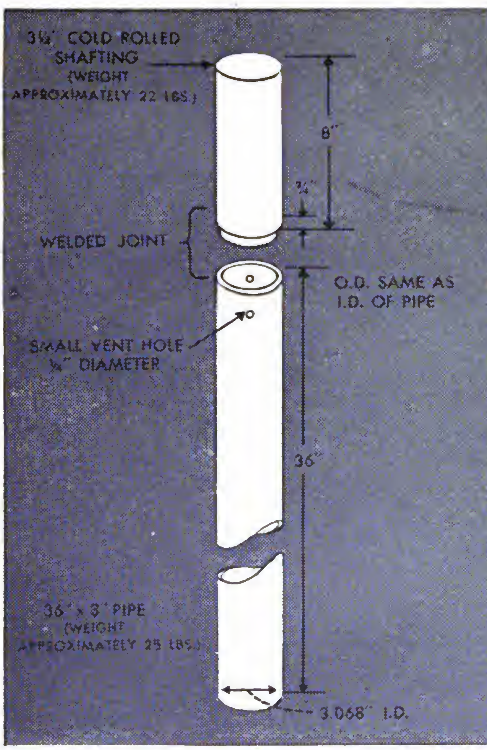


Figure 14. Details of driver shown in figure 13.

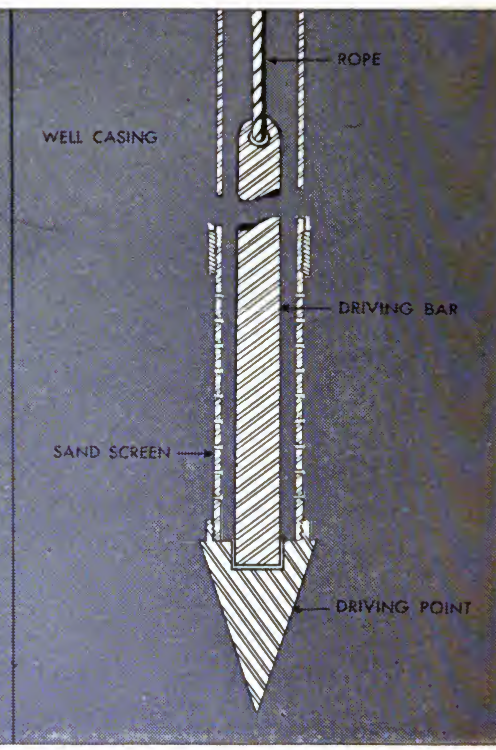


Figure 15. Cross section of drive point with driving bar that delivers blow on point.

(3) A maul or sledge striking directly on a drive cap fitted over the pipe. The operator must deliver even blows to the drive cap or the pipe will break (fig. 16).

(4) A pneumatic tamper or sheet pile driver from an air compressor, provided the pipe is strong. A weak pipe will break at the couplings, particularly if butt-joint pipe is not used.

(5) A drive monkey that slides over the pipe. The simplest arrangement (fig. 17) is one in which the drive monkey slides over a bar or pipe supported by the well pipe itself. An alternate method is to allow the drive monkey to slide over the well pipe itself as shown in figure 19. In this second method a drive clamp placed around the well pipe is used instead of a drive cap on top of the pipe. A tripod, illustrated in figure 19, can be employed with either of the methods for using the drive monkey.

d. Too much stress cannot be laid upon the importance of making airtight joints in driven wells. In the driving process, all joints should be screwed tightly after they are carefully cleaned, oiled, burs and bruises are removed, a light coating of white lead is applied. Protection of the threads by caps or couplings during transportation and storage is advisable. When the pipe is being driven with difficulty, the whole string of pipe is twisted frequently to tighten the couplings.

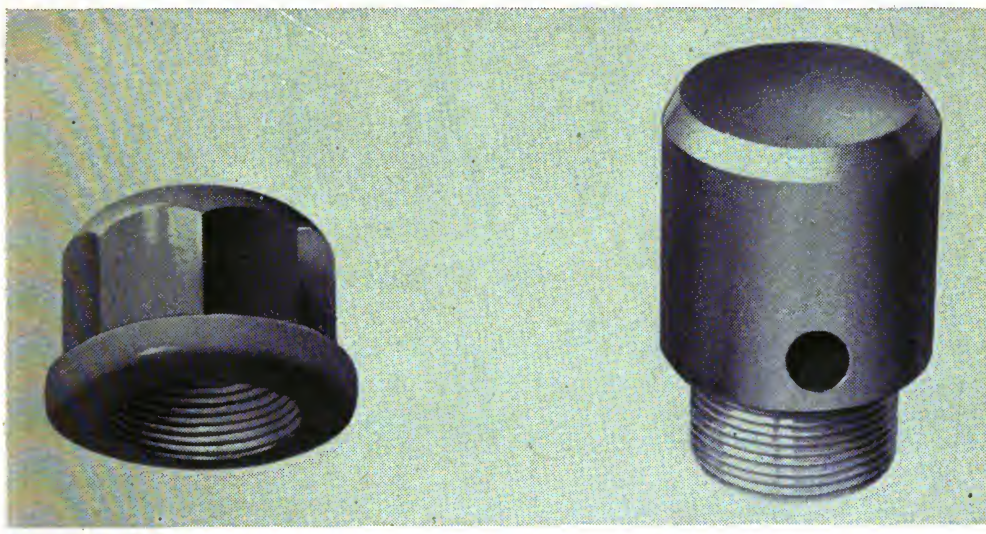


Figure 16. Drive caps for use with sledge, maul, or air hammer. Cap at left fits over pipe, while type at right fits inside pipe.

e. It is essential that the well pipe be kept vertical. Until the first two sections of the drive pipe are in place, this should be checked constantly by a plumb bob held at arm's length from the well pipe, and from two directions at approximately right angles to each other. If the pipe is slightly out of vertical during the early part of the driving, it generally can be pushed into place by pressure exerted on the pipe while the blows are delivered. Unless it can be straightened, the pipe is withdrawn and started again in a new place.

Figure 17. Simple pulley and weight apparatus for driving wells.

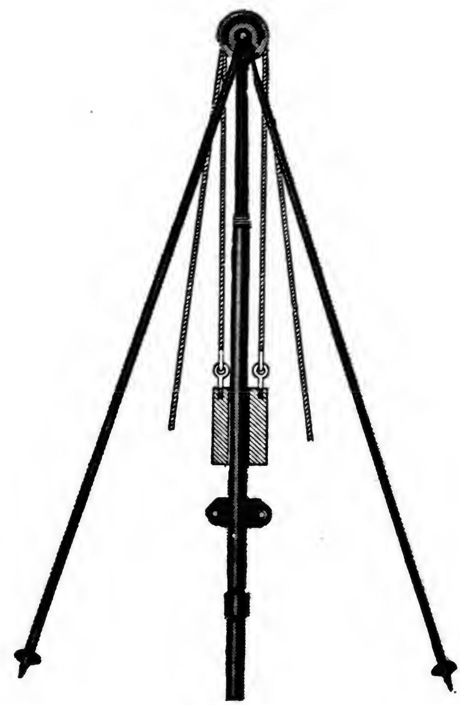


Figure 19. Tripod arrangement for driving wells.

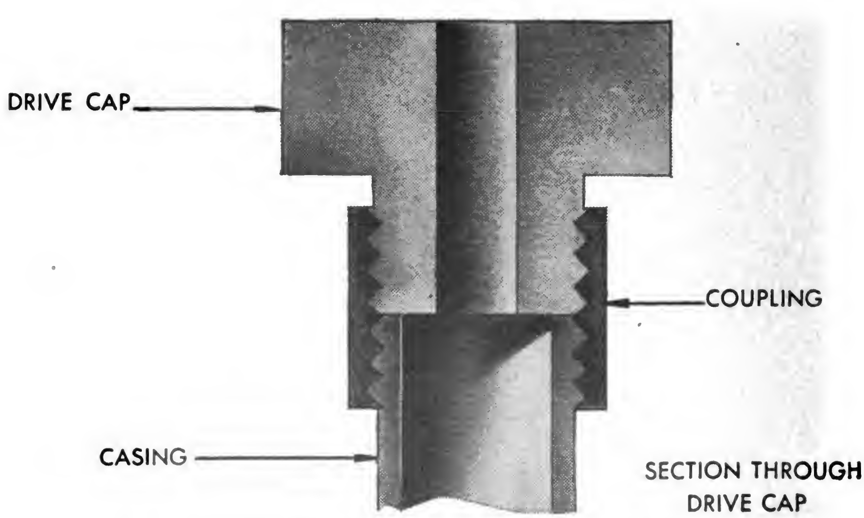


Figure 18. Drive cap for use with apparatus in figure 17.

22. RATES OF DRIVING.

a. In soft formations the rate of descent normally is 2 or 3 inches per blow, and a total time of 5 minutes per well is common under the best conditions. Driving in compact clays often is facilitated by introducing water into the pipe or around it, and in some formations the pipe always is rotated a fraction of a turn at each blow. Extremely tough clays are difficult to penetrate, and dozens of blows may drive the pipe only a few inches.

b. Successful construction of driven wells depends upon close observation and correct interpretation of events while driving. Accurate interpretation of such details as the penetration made with each blow, the drop and rebound of the monkey, the sound of the blow, and the resistance of the pipe to rotation, enables the experienced well driver to determine the character of the materials being penetrated. An approximation of the geological section of the well can be obtained by recording these observations. Study of the logs for successive wells, coupled with a study of the results obtained from each well, assists in developing trained operators. A guide to the type of formation which is penetrated by drive points is as follows:

(1) Soft, moist clay gives easy driving; rapid descent; a dead blow without rebound; a dull-sounding blow; and a slight but decided and continuous resistance to rotation.

(2) Tough, indurated clay gives hard driving; slow progress, but appreciable descent at each blow; no resonance; considerable, but silent and continuous resistance to rotation, and causes frequent rebounding of the monkey.

(3) Fine sand usually is hard to penetrate whether wet or dry, and gives some resistance to rotation accompanied by a slight gritty sound transmitted up the pipe. There is frequent rebound of the monkey with a dull resonance.

(4) Coarse sands often are easily penetrated, especially when saturated with water. Progress often is unsteady, with irregular penetration for successive blows. Rotation is easy and is accompanied by a gritty sound. There is no rebound of the monkey after a stroke.

(5) Gravels generally give easy driving, but irregular penetration for successive blows. Rotating the pipe gives a gritty sound with irregular resistance as pebbles are pushed aside. The pipe generally is free after a few revolutions.

(6) Boulders and rock give little or no progress and cause rebound of the monkey and some times of the pipe. Rotation is easy unless the pipe is out of plumb. There is loud resonance at each blow.

23. DEVELOPMENT OF FREE FLOW.

a. Although a well site may have been properly selected, the strata correctly interpreted, and the presence of water accurately judged, wells

may fail to yield water merely because they have not been pumped to clear the fine sediment from around the screen. When the presence of water is suspected, a simple test is to pour water into the well. If the screen is in dry sand, the water sinks downward and seeps into the formation, but if the screen is in saturated sand, the level of the added water remains nearly stationary or quickly sinks to a static level. Also the quantity of water that can be poured into the well is an index of the well capacity when pumping; when saturated, the sand yields its contents as freely as it absorbs water. Often the raising or lowering of the pipe a foot or more brings a greater length of the screen into contact with the water-bearing stratum and results in a great increase in yield.

b. If the lower part of the pipe is choked with fine detrital matter that might prevent the water from entering, it can be cleaned out by one of the three following methods:

(1) Attach a hand pump to a string of ½-inch pipe that has been lowered inside the well pipe and clamped in position with the lower end of the small pipe resting on the sediment in the well. Run water into the well between the drive pipe and the ½-inch pipe and start the hand pump. By steadily lowering the ½-inch pipe and adding water while continuing pumping, material that obstructs the free entrance of water into the casing may be removed.

(2) Insert a string of ½-inch pipe, fill the well with water, and repeatedly raise and lower the ½-inch pipe sharply by hand. By holding the thumb over the top of the ½-inch pipe during the upward movement and removing it during the downward movement, a jet of muddy water is expelled at each downward stroke. A bailer can be improvised by using a marble or a ball bearing for a check valve. When the material has been loosened and put into suspension, the muddy water can be pumped out.

(3) Water pumped into a string of ½-inch pipe reaching down to the accumulated sediment acts as a water jet to break up and remove it. This procedure requires an auxiliary motor-driven or hand force-pump.

c. The common pitcher-mouthed kitchen pumps usually supplied for drive-point wells are of the suction type, with a lower valve that can be tripped by raising the pump handle high enough to cause a projection on the bucket to strike the hinge side of the suction valve. It is, therefore, possible not only to prime the pump but to run water into the tube itself by tripping the lower valve. By alternately applying a heavy suction on the well and tripping the valve to allow the water to rush back, a maximum disturbance is created in the well. Even if there is only a tiny flow of water at first, the stratum from which it comes tends to break down from the repeated pressure; and the relief gradually induces the ingress and

egress of small quantities of water, removes the smaller grains of sand, and finally breaks down the sand body. This is at once followed by an inrush of muddy liquid in which fine particles predominate. Continued hard pumping for a few minutes generally causes a continued inrush of sand and water, during which the grains of sand steadily increase in size. It is very important at this stage to use relays of men to maintain a rapid rate of pumping; otherwise the sand settles and plugs the lower part of the well pipe. After a time the water without sediment flows easily and freely; the well is then ready for use. Failure of a well to develop a usable supply of water may be due to closely compacted, ungraded sand grains that do not readily break down, although saturated with water. Or the driving of the well point may have consolidated an already closely packed sediment.

d. Difficulty may be caused at this stage by a heavy mass of sand settled on the valve seating, and especially by jamming in the bucket-valve guides, throwing the pump out of action till cleared. For this reason it is advisable to employ pumps with which access to the bucket-valve is possible without removing a top piece. Sand grains of medium size are the most objectionable in this respect, and both before and after the expulsion of this grade which binds the bucket-valve in its guides, the process is more simple. Ultimately, after from ½ to 2 hours' pumping in cases where fairly large perforations are used, particles the size of peas rise with the water, which by then is nearly clear. It sometimes may be necessary to remove the pump and clean out the point with an improvised bailer.

e. Under the above conditions it is often impossible to develop a well if a fine screen is used. The small orifices become clogged so firmly that they do not allow the full benefit of the pump action, and they do not permit the sand bodies to break down sufficiently to induce a useful inflow of water. Such sands yield large quantities of water only when the small particles have been abstracted for an appreciable distance around the well. This leaves a residue of coarse material that could not enter the tube but which readily allows the movement of water toward the perforated point.

f. Where the water level does not rise sufficiently high to permit using a suction pump, it is possible in some cases to sink a shaft sufficiently deep to permit the attachment of a pump barrel within reach of the water.

g. Once a natural packing has been formed, it is disturbed as little as possible or sand trouble constantly may recur. If the well is not deep enough for the point to escape surface vibration during pumping, the pump is fixed firmly to stout posts or otherwise supported. For the same reason the water level never must be lowered below the sand from which the water is drawn, otherwise the movement of water along the perforations

might upset the natural packing which was formed under water. When wells operate under such conditions, trouble may arise from the recurrent entry of sand.

h. Entry into water-bearing stratum usually is indicated by an immediately increased rate of descent, sometimes as much as 6 inches at a single blow, but when the water-bearing sands are fine-grained, there may be little or no increase in the speed of penetration. On entering a suspected water-bearing sand, driving is stopped and a plumb bob lowered to ascertain if water has entered the well. If little detritus is found in the pipe, and the level of the water stands well above the perforations of the screen and within 15 to 20 feet of the surface, the pitcher pump may be attached, and a test made to determine the yield.

24. SINGLE AND MULTIPLE WELLS.

a. The yield from a single drive point well is small, generally only a few gallons per minute; the maximum under exceptionally good conditions ranges from 20 to 40 gallons per minute. Batteries of these wells connected with a single suction header, however, supply relatively large quantities of water. The wells should be staggered on opposite sides of the header, and the minimum distance between wells should be about 30 feet. This type of installation is best suited to conditions where the water-bearing formation is free from large gravel and boulders and where water is not more than 10 or 15 feet below the ground surface. In formations of limited thickness, driven wells often give the best results. They can be used in thick water-bearing formations but other types are more effective. If the draw-down is sufficient to permit the suction of air into the well points, the natural gravel pack around the well point is disturbed and sand is pumped from the well. If batteries of wells are located in coastal areas where the fresh water floats freely on the salt water, they should never be pumped heavily enough to draw the water table down to sea level in any of the points.

b. The union of two wells to a common suction ordinarily is effected by placing the pump at a point intermediate between the two thus equalizing the suction, but the coupling of a number of wells requires more care to insure equal suction at all wells. When the water table is near the surface, there are usually no difficulties in group pumping; but with a water table of 15 to 20 feet below the surface, air locking in the horizontal pipe may cause trouble in starting the pump. Relief can be obtained by introducing at each well a valve that is opened successively only after the air has been removed from each preceding well. The valves also permit priming by filling with water from a point near the pump.

c. A check valve is inserted in the line to each well to keep the service primed after once being put into operation. A useful expedient where the type of pump does not permit a short high-speed run which helps to remove the air, is to fit each well with a ball valve just above its well point. The pressure in the pipes on standing then insures a tight fit that restricts leakage of water if air gets into the pipes. Usually it is possible to determine whether the wells are all working by noting the temperature of the pipes at the various wells. By placing a rod between the pipe and the ear, usually it is possible to detect clearly the sound of flowing water in those pipes through which it is passing. Failure to start a group service nearly always can be attributed to the influence of air, and remedies must be sought to effect its removal and to prevent its readmission.

d. If only a few well points are to be installed, probably the best method of installation is driving. However, when a battery or several batteries of well points or small wells are to be installed, a modification of the process usually is desirable. The first few wells of a battery are placed in the manner of test points; and after the characteristics of the water-bearing sand have been determined, the remainder of the wells can be installed by augering with or without jetting, or by jetting alone.

25. REMOVING PIPE. Well points and pipe may be withdrawn by upward blows with the drive monkey on a pipe clamp attached firmly to the well pipe, by levers or jacks working against a pipe clamp or pipe-puller head, or by a chain wound around the drive pipe and connected to one end of a long lever operating against a solid fulcrum. After the pipe has been raised a few feet, often the remainder of the lift can be accomplished by hand, and in general it is advisable to turn the pipe from time to time to assist in pulling.

26. DRIVE POINTS.

a. Drive points are made in a variety of types and sizes (fig. 20). Standard form points consist of perforated sections of standard galvanized pipe with close-fitting jackets of punched gauze and woven mesh. They are fitted accurately with sharp carbon steel tips that pierce the soil and open up a passageway for the point as it is driven into the ground. Drive points are so constructed that the intake area through which water passes is relatively small. The perforated pipe must of necessity be strong, and the number and size of perforations are limited accordingly. These holes determine the effective intake area; that portion of the jacket lying against blank pipe is plugged practically by the pipe itself, admitting very little water into the well column. This condition may be corrected somewhat by the use of a loose-fitting jacket, but such a jacket is much more likely to be stripped from the point as it is driven into the ground.

b. Drive-point jackets of the mesh type are double; wire cloth lies next to the pipe and is covered by perforated brass sheeting. Usually the holes in the mesh cloth are square; and those in the brass sheeting are round. However points with slotted outer jackets are available. Drive points are classified by the size of the mesh of the inner jacket; sizes 40, 50, 60, 70, and 80 (numbers of screen apertures per inch) commonly are used (fig. 21). The choice depends entirely upon the sizes of particles in the water-bearing stratum; unless very fine grains predominate, the highest yields are obtained with mesh of size 60 or larger.

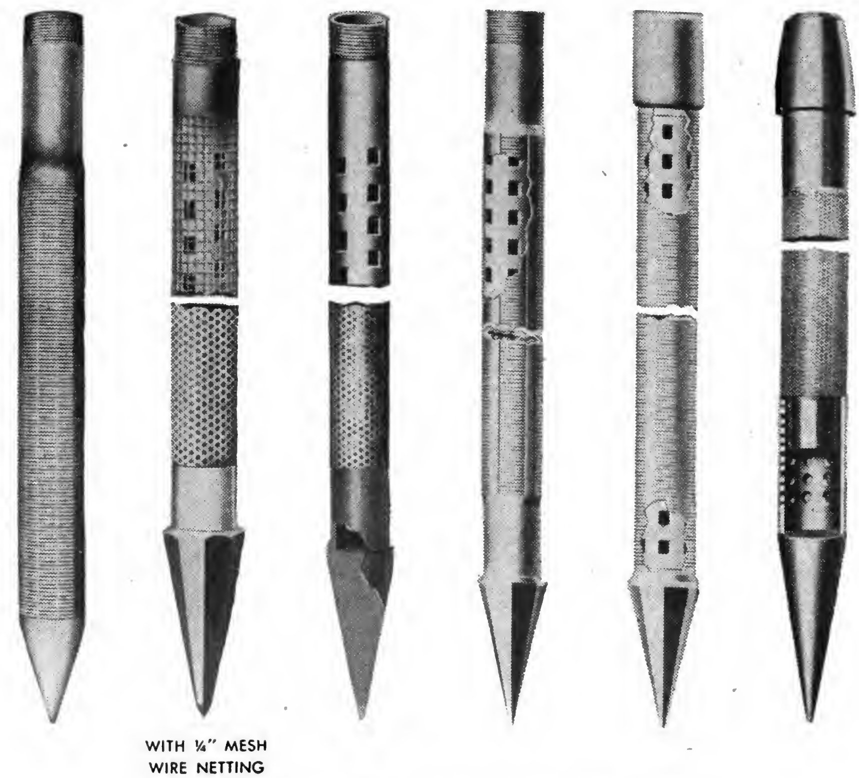


FIGURE 20. *Types of driven well screens and points.*

CHAPTER 6

INTRODUCTION TO DRILLING METHODS

SECTION I

GENERAL

27. CONDENSED DESCRIPTIONS OF CHIEF METHODS.

a. General. This chapter is a brief introduction to the hydraulic rotary and percussion tool methods of drilling. It gives their general characteristics, the major differences between the two methods, and information on their appropriate use under different drilling conditions. Chapters 7 and 8 describe the two methods in detail.

b. Hydraulic rotary method. (1) With the hydraulic rotary method drilling is accomplished by rotating suitable tools that cut, chip, and abrade the rock formations into small particles. The equipment used consists of a derrick, suitable cables and reels for handling the tools and lowering the casing into the hole, a rotary table for rotating the drill pipe and bit, pumps for handling mud-laden fluid, and a suitable source of power. As the drill bit attached to the lower end of the drill pipe is rotated, circulating mud is pumped through the drill pipe, out through openings in the bit, and up to the surface through the space between the drill pipe and the walls of the hole. The mud-laden fluid removes the drill cuttings from the hole and also prevents caving by plastering and supporting the formations that have been penetrated. For soft and moderately hard materials a drilling tool shaped like the tail of a fish, the "fishtail bit," is used. In hard rock a "rock bit" or "roller bit" is substituted. This bit has a series of toothed cutting wheels that revolve as the drill pipe is rotated.

(2) Water wells drilled by the hydraulic rotary method generally are cased after reaching the required depth, the complete string of casing being set in one continuous operation. If the water-bearing formation

lies so deep that it probably cannot be reached by a hole of uniform diameter, the hole is started one or more sizes larger than the size desired through the water-bearing formation. Separate strings of casing are used as required through the separate sections of the hole. If the formation is so well consolidated that the hole will remain open without casing, a well may be finished with one string of casing and a well screen.

c. Cable-tool percussion method. In the cable-tool percussion method of drilling, the hole is constructed by the percussion and cutting action of a drilling bit that is alternately raised and dropped. The drill bit, a clublike, chisel-edged tool, breaks the formation into small fragments; and the reciprocating motion of the drilling tools mixes the loosened material into a sludge that is removed from the hole at intervals by a bailer or sand pump. The drilling tools are operated by suitable machinery, which is usually of the portable type mounted on a truck or trailer so that it can be moved readily from job to job.

d. Casing. **(1)** The hole is cased with lengths of wrought-steel casing connected by screw and socket couplings. Casing has five purposes:

(a) To prevent caving of the hole after completion.

(b) To permit the drilling of a hole through inclined or creviced beds.

(c) To exclude highly mineralized water or water of inferior quality from upper formations.

(d) To prevent the loss of high-pressure water into low-pressure intermediate sands.

(e) To prevent the entrance of shallow ground water, surface water, or waste that would contaminate the well-water supply.

(2) The wells usually are cased as drilling proceeds; however, under some conditions the casing may be set in one string after the hole has been drilled. The casing may be of the same diameter through its entire length; but if caving formations, casing difficulties, or other problems prevent continuing the hole at the original size, the diameter may be reduced one or more times as required, strings of smaller casing being set in each section of smaller hole. A well drilled in consolidated material may be cased only throughout the upper portion, being finished as an open hole. On the other hand, a well drilled in unconsolidated material, such as sand or gravel, generally is finished with a screen to prevent the sand or gravel from entering with the water.

e. Well screens and points. **(1) General.** **(a)** All modern wells obtaining their supplies from unconsolidated materials are finished with well screens or strainers. The primary purpose of a properly constructed well screen is not to prevent the entrance of all sand but rather to permit the fine sand to enter so it can be removed, and to hold out the large particles so they will build up into a natural gravel screen around the well

tube. In this way the permeability of the water-bearing material around the well is greatly increased, resulting in a greater yield for the well. If the water-bearing material is composed of a fine-grained sand that normally would require very fine openings in the screen to separate it from the water, the yield of the well may be increased by inserting selected gravel of uniform size around the well tube. This type of well is known as a gravel-wall or gravel-packed well.

(b) Well strainers may be divided into two classes: points that may be driven into place, and screens that must be set into place. The distinction is highly significant; drive points (par. 26) are designed primarily to withstand the abuse involved in driving them beneath the water table. Screens, on the other hand, cannot withstand undue abuse; they are designed solely to develop high intake efficiency and to secure the highest possible yields per foot of screen.

(2) Well screen. **(a)** Well screens are highly specialized types of well equipment. Except that they form the lower portion of the well column, they are in no sense well points; they are designed and constructed to secure the highest possible yield from the water-bearing strata into which they are placed. Standard well screens are strongly constructed and will withstand any kind of ordinary abuse short of driving; but they do not have a driving point and must be set into place by means of a casing or by bailing.

(b) Two principal types of well screens are on the market at the present time: screens milled from solid tubing and continuous-slot screens.

1. Tubular milled screens are identical with the jacket previously described in connection with specialized drive points; in fact, that type of drive point is assembled simply by adapting the tubular milled screen to it. When used as a true well screen, the milled tube has no interior reinforcement of any kind. Screens of this sort always are constructed on the nonclogging principle; they are manufactured with slot sizes ranging from 0.004 to 0.10 of an inch (fig. 21). This wide range in slot sizes makes it possible to choose screens to match the grain of the stratum into which they are to be placed. Standard diameters range from 2 to 12 inches, and any length may be had up to 17 feet. Standard pipe fittings are supplied. Tubular well screens prove very satisfactory. They have high capacities; and as no interior reinforcement interferes with the flow of water, each individual slot is effective.

2. The continuous-slot screen differs greatly from all other types of well equipment. It is constructed of a narrow ribbon of metal wound spirally around a skeleton of longitudinal rods,

each point of contact of the ribbon and rods being electrically welded. The screen is, therefore, a single strong, stiff, firm piece. It gives the highest percentage of open-slot area possible in well screens. For yield, continuous-slot screens are the best and most satisfactory type of well strainer. Practically all of the continuous slot is open and available for the

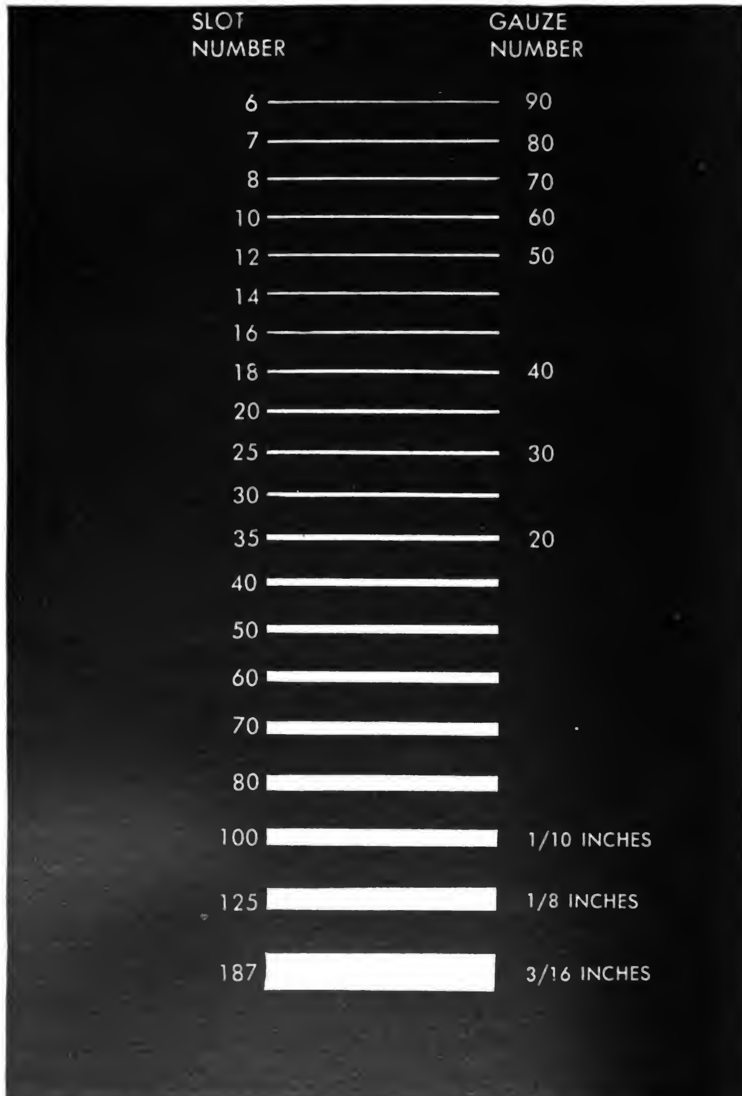


Figure 21. Slot sizes of well screens.

passage of water; the only blank portions are the small points of contact of the ribbon and rods closed by the weld. Any slot size may be supplied, the opening being determined by the spacing of the metal ribbon as it is wound onto the rods. Standard slot sizes range from 0.006 to 0.125 inch. All screens of this kind are built on the nonclogging principle.

Stock diameters range from 3 to 12 inches, and any length up to 16 feet is considered standard. The continuous-slot screen has a number of important advantages over the tubular screen. It is stronger and will stand more abuse; and, size for size, it gives equal or higher yields under the same field conditions. It has 30 to 100 percent more intake area per linear foot than screens of other kinds of the same sizes.

(c) Well screens are intended for permanent installation; consequently standard factory fittings are not suitable for screens placed in temporary wells. Satisfactory ends can be made from standard 2-inch pipe. A short, threaded section is welded to the lower end of the screen and capped, and a similar piece welded to the upper end for attachment with the well pipe. Screens are made from a variety of metals. In corrosive waters, brass is used. Everdur metal, Monel metal, and Abrac also are recommended. Armco iron and galvanized steel are suitable for non-corrosive waters. When fabricated screens are not available, a well can be finished with a length of ordinary casing perforated and placed in the water-bearing formation.

SECTION II

CHOICE OF DRILLING EQUIPMENT

28. GENERAL CONSIDERATIONS.

a. Any well-drilling operation requires a thoroughly trained and experienced driller. Drilling conditions and drilling problems are so variable that there is no substitute for a wide and varied experience. A man may be an expert in drilling technique in one locality but completely unqualified if moved without notice into an area in which he is inexperienced.

b. Recognizing and locating the water-bearing strata presents operating problems entirely different from those encountered in seismograph or structural drilling. The drilling technique is fundamentally the same; but the speed with which the work is done, the care with which samples are collected and the logs recorded, and the time spent in testing differ widely.

29. STATUS OF GEOLOGICAL INFORMATION.

a. If the driller or his supervisors are thoroughly familiar with the geology of the area being developed and know in advance where the water-bearing formations are to be found, the drilling can be conducted according to a set plan. The hole can be drilled rapidly to the water-bearing bed, the casing set and cemented if necessary, and the well put into production.

b. If, however, the geology of the area is imperfectly known and it is necessary to search for unknown water-bearing beds, the work is different. The drilling must be careful and deliberate, and all possible water-bearing horizons must be tested carefully. Such a search calls for proper equipment, and trained and experienced men.

c. Often water-bearing beds are difficult to recognize, and careless or inexperienced men frequently pass them up. Many wells capable of producing water are abandoned as dry as a result of incompetent drilling.

30. DETECTION OF WATER WHILE DRILLING.

a. The rate at which water enters the hole depends on the permeability of the formation and the hydrostatic head on the water. The height to

which the water rises in the hole depends primarily on the hydrostatic head. Water under high hydrostatic pressure is much easier to locate during drilling than is that under low hydrostatic pressure, because the high pressure tends to force the water into the hole against the pressure of the mud or drilling fluid being used.

b. A "tight" zone (one of low permeability) produces less, even under high pressure, than an "open" (highly permeable) one under low hydrostatic head. The detection of highly permeable "open" zones under low hydrostatic pressure is therefore most important, even though difficult, and controls the entire procedure of prospecting.

c. In the rotary method of drilling the bore hole is kept full of a relatively heavy mud fluid. The pressure of this fluid against the walls of the hole and against the water-bearing beds is generally higher than the hydrostatic pressure of the water in the zone; hence the mud fluid tends to penetrate and seal the pore spaces. Water under low hydrostatic pressure, therefore, does not force itself into the hole, and unless care is taken, such zones may be passed up as dry.

d. In cable-tool or percussion drilling generally the hole is not kept full of mud or water, and low-pressure water sands are much easier to detect. The water is allowed to seek its own hydrostatic level; hence generally the hole contains only clear water plus the sand or mud produced during the drilling. Thus clogging of the walls is minimized and water under low pressure made easier to detect. However even in cable-tool holes care must be taken to avoid passing up low-pressure zones.

e. The level of the water in the hole does not indicate the quantity available. For if the hydrostatic head remains the same, the level assumed during drilling through relatively "tight" formations incapable of producing much water is not altered when the drill penetrates a "loose" or permeable zone capable of producing great volumes of it.

f. In cable-tool holes usually it is relatively easy to estimate the quantity of the water by bailing. The bailer is run rapidly and the level of the fluid determined at each run. However, in a loose zone with prolific water supply the fluid level cannot be reduced by bailing, and a pumping test must be made. When the required volume of water is discovered, the well can be cased and put into production.

g. Testing of water-bearing formations is discussed further in chapters 7 and 8.

31. ROTARY AND PERCUSSION DRILLING COMPARED.

a. General. There has been considerable controversy as to the relative merits of the rotary and cable-tool methods of drilling and prospecting for water. Under certain conditions, cable tools *must* be used; under other conditions rotary drilling *must* be used.

(1) Cable tools are unsatisfactory and at times unusable in soft, loose-unconsolidated materials such as dune sand, quicksand, and unconsolidated river gravels; they are especially bad for drilling deep, small, diameter holes in such materials. The pounding of the drill, the low fluid level, the unsupported open hole above the fluid, and the lack of mud sealing, all contribute to slumping and caving. In Arabia, wide areas are encountered in which the cable-tool spudder (Star spudder, model 71) cannot be used. The hole simply cannot be kept open.

(2) On the other hand, small rotary machines are unsatisfactory and at times unusable in cavernous or extremely permeable lost-circulation zones. However if the lost-circulation zone is thin or if the pore spaces are relatively small, many expedients are available for trying to regain circulation. Sometimes cement can be forced into the zone and allowed to set. If the pore spaces are large or if small caverns are encountered the extremely viscous aquagel-cement may be used for this purpose. Another possibility is the addition of chopped straw, cottonseed hulls, chopped hemp, burlap sacking, or other fibrous material to the mud fluid to assist in clogging the pore spaces or small caverns or cracks.

(a) Once such expedients have been used, care must be taken in all later drilling to keep the hole full of mud in order to keep a constant pressure against the side walls. The cement or fibrous material is only a temporary dam sealing the walls of the hole and if the fluid pressure inside the hole is allowed to drop even momentarily below the hydrostatic pressure of the water in the formation, the dam may be forced into the hole by the pressure of the fluid on the outside. Then when the hole is filled with mud preparatory to resumption of drilling, the circulation is again lost into the same zone.

(b) When a known lost-circulation zone is to be penetrated, it may be possible to drill into the zone, work through it with one of the expedients mentioned, run a string of protective casing, and then firmly seat or cement the casing in place. The hole is thus protected from slumping or loss of circulation. In some areas, however, none of these expedients will work and the rotary rig cannot be used.

(c) In the Dhahran area in Arabia the failure of the rotary rig made it necessary to drill 40 holes with the spudder. The ground-water level stood about 250 feet below the surface, and the overlying formation was a continuous section of dry cavernous limestone. None of the expedients mentioned above would work; so the entire job was completed by spudder.

b. Special conditions. **(1)** In another place a cavernous lime-cemented bed was beneath about 40 feet of loose dune sand, and under the cavernous zone was a thick body of very loose unconsolidated sand and gravel. The spudder could not handle the upper layer of dune sand,

but it was easily penetrated by the rotary. The instant the cavernous zone was encountered, however, the circulation was lost and the hole caved in. Another attempt was made. This time the rotary drilling was suspended about 3 feet above the cavernous zone and a casing run into the hole. Then the spudder was moved in. It drilled through the cavernous zone, driving the casing with it, until the soft formation below the cavernous zone was encountered. Then it drilled about 10 feet below the bottom of the cavernous zone but was then making such slow progress that the casing was driven to a tight seat and the rotary was used to carry the hole to a depth of 350 feet in the loose material. Several subsequent holes were drilled in the same area, and this same procedure was followed in all cases.

(2) Desert conditions also present a special problem. The physiography, topography, and surficial materials of desert areas throughout the world are remarkably similar. Wide alluvial fans spread out from the hills and mountains across the lowlands. In many places the alluvial fans consist of relatively coarse detrital material ranging in size from boulders and cobbles to gravel and coarse angular sands, with only minor amounts of clay and silt. Dune sands and thick covers of wind-blown sand are common.

(3) The central parts of the lowlands frequently consist of dry lake beds (playas) in which clays, silts, and finer sands are concentrated, the whole being impregnated with salt and gypsum and filled with saline water. If there are limestones or dolomites at shallow depths, generally they are cavernous, particularly in sections lying above ground-water level. If thick mud and occasional fibrous material are used, the small rotary rig can drill through the ordinary alluvial fans much more rapidly than can cable-tool drills. Generally the pore spaces are small and the mud and fibrous material clog and seal them off. Hence the cable-tool spudder frequently has great difficulty with caving of the hole, and progress even under the best conditions is slow.

(4) Boulder beds in alluvial fans or in glacial drift are extremely hard to drill by any method. Drillers in Canada have encountered boulders and cobbles in glacial drift that could not be handled successfully by small rotary machines. Some progress was made by "worrying" down an oversize hole about 10 feet, then driving a 10-foot joint of pipe, and repeating as far as possible; but the process was unsatisfactory and uncertain. A spudder would have been more satisfactory, because driving the pipe and keeping the casing shoe close to the drill bit would have been easier. However, even the spudder sometimes fails under such conditions. At best, they are extremely hard to handle.

(5) Dunes and other wind-blown sands are handled easily with rotary

machines, but slumping of the hole makes it difficult to handle them with cable tools.

(6) The clays and silts of dry lake-bed areas frequently are interbedded with quicksand. The rotary machines handle these materials rapidly and easily. The spudder easily handles clays and silts, but it is seriously handicapped, if not inoperative, in quicksand.

(7) In hard sedimentary rocks such as limestone, dolomite, lime-cemented sandstone, and hard calcareous shales the small rotary with rock bits (roller-bit types) makes slow progress at the top of the hole where the weight of the drill pipe is not sufficient to force the rotating bit against the rock. Hence most small rotary machines have a "pull-down" device on the drill stem making it possible to add the weight of the drill rig to that of the drill pipe. This auxiliary device is a necessity for rapid progress and should be incorporated in every drill machine. As the hole gets deeper, the weight of the drill pipe is greater and the progress is improved. Cable-tool spudders, on the other hand, maintain about the same speed of drilling at all depths in such material. Metamorphic and igneous rocks can be handled at reasonable speed with rotary machines; rotaries also are used in diamond-drill prospecting. Cable-tool spudders also can handle such material. Chert nodules occasionally are encountered in sedimentary rocks. They are a hard, brittle silica glass and hence are particularly difficult to handle with the small rotary machines. The rotary bit grinds and polishes the upper surface of the nodule, and thereafter the teeth of the bit simply slide on the polished surface. Progress is extremely slow, and the cone bearings wear out rapidly. The spudder can handle this hard but brittle chert much faster than can the rotary machine. The performance of rotary and percussion equipment is summarized in table I.

Table I. Rotary and percussion drill performance

Type of formation	Relative drilling performance	
	Rotary drill	Percussion drill
Dune sand	Rapid	Difficult to impossible.
Loose sand and gravel	do	Do.
Quicksand	do	Difficult to impossible except in thin streaks. Requires a string of drive pipe.
Loose boulders in alluvial fans or glacial drift.	Difficult, frequently impossible.	Difficult—slow but generally can be handled by driving pipe. Frequently impossible.
Clay and silt	Rapid	Slow.
Firm shale	do	Rapid.
Sticky shale	do	Slow.
Brittle shale	do	Rapid.
Sandstone—poorly cemented	Slow	Slow.
Sandstone—well cemented	do	Do.
Chert nodules	do	Rapid.
Limestone	Rapid	Do.
Limestone with chert nodules	Slow	Do.
Limestone with small cracks or fractures.	do	Do.
Limestone, cavernous	Slow to impossible	
Dolomite	Same as limestone	Same as limestone.
Basalts, thin layers in sedimentary rocks.	Slow	Rapid.
Basalts—thick layers	do	Slow.
Metamorphic rocks	do	Do.
Granite	do	Do.

c. Speed of drilling. (1) In most oil prospecting, speed of drilling is much more important than cost per foot of hole, because it is of paramount importance to be able to evaluate the area at the earliest possible moment.

(2) The small rotary has proved much the faster of the two methods under all ordinary drilling conditions. Therefore small rotaries have been adopted almost universally for seismograph and structure-hole drilling, and whenever possible in water-well drilling and shallow-oil or gas-well drilling. In areas where either method is satisfactory, generally the spudder is somewhat cheaper per foot of hole drilled; but the difference is not great, and the advantage of greater speed has turned the industry to rotary methods in all but minor jobs and in areas underlaid by cavernous limestones.

(3) In the San Joaquin Valley of California it is not unusual for light rotary machines to drill 100-foot holes, 5⅝ inches in diameter, at the rate of 700 feet of hole per day, with an estimated working average of

about 500 feet of hole per day. The formation is soft firm clay, silt, and sandy clay. Such conditions are ideal for rotary drilling; here the spudder would fall hopelessly behind. Also in Alberta, Canada, an average of 500 feet of hole per drill per day has been achieved. The surficial formations are somewhat harder than in California.

(4) Comparison of the performances of these small drills with those of heavier machines is difficult, because the heavy machines are used to drill larger-diameter holes to greater depths. But the larger machines are so much slower to move and set up that down to the limit of their depth the small seismograph machines can drill many more holes and many more feet of hole per month.

(5) The spudder and the rotary require about the same time to dismantle, move, and set up ready for drilling. If the holes to be drilled are close together, a move with either drill can be made in a few hours. If the holes are widely spaced, a move may require much longer.

d. Drilling water requirements. **(1)** The spudder requires much less drilling water than does the small rotary. In normal operation it can get along with 100 to 150 gallons of water per 8-hour tour or shift. When drilling in lost-circulation zones the small rotary may require much greater quantities of water. In normal operations, a tank truck holding 750 to 1,000 gallons can haul water from a distance of 100 miles or more to keep such a machine running.

(2) At the start of operations in an area more than 100 miles from water, if time is not important, it may be advisable to drill the first hole with a spudder, rather than haul water; then after the spudder well is in production, the rest of the holes can be drilled with the rotary machines.

(3) The quality of water is not critical for either machine. Fresh water makes the best rotary mud, but in an emergency almost any water can be used. Sea water has been used to drill rotary holes. Sea water and brines are hard on equipment, tanks, pumps, trucks, valves, etc., and their mud is flocculated or "curdled"; but holes can be drilled with it. The spudder also can use sea water or brines. In fact, in spudder operation in soft heaving shales, clays, or bentonites (particularly soft "soluble" shales) it is common practice to saturate the drilling water with salt and to pour rock salt into the hole. The salt in solution prevents the dispersion or suspension of the clay.

CHAPTER 7

ROTARY DRILLING METHOD

SECTION I

GENERAL DESCRIPTION

32. ELEMENTS OF ROTARY DRILLING.

a. Small efficient rotary machines have been developed in recent years which in general drill faster than the percussion type and with the use of the improved roller type bit can be used to drill all but a few formations.

b. Rotary drilling requires a cutting tool or bit, a means of imparting a rotary motion to the tool, a means for maintaining bit pressure against the material being cut, and a means of removing the material or cutting displaced by the bit. These factors produce a movement of the cutting tool into the material being cut, commonly referred to as "making hole." The rotary system of drilling is illustrated in figure 22.

c. In all types of drilling, the bit or boring tool must be rotated at a reasonably uniform speed and fed at a regular rate under uniform pressure.

33. BASIC COMPONENT OF THE MACHINE.

a. The drill bit is revolved by a steel pipe or drill pipe, extending from the drill bit to a point some distance above the ground. The grooved or fluted top joint of the drill pipe, the "kelly," passes up through the drill-head drive rod, to which it is connected by a kelly drive bushing. This bushing is grooved to fit the splines on the kelly, which thus can rotate and move vertically at the same time. The drive rod is rotated by bevel

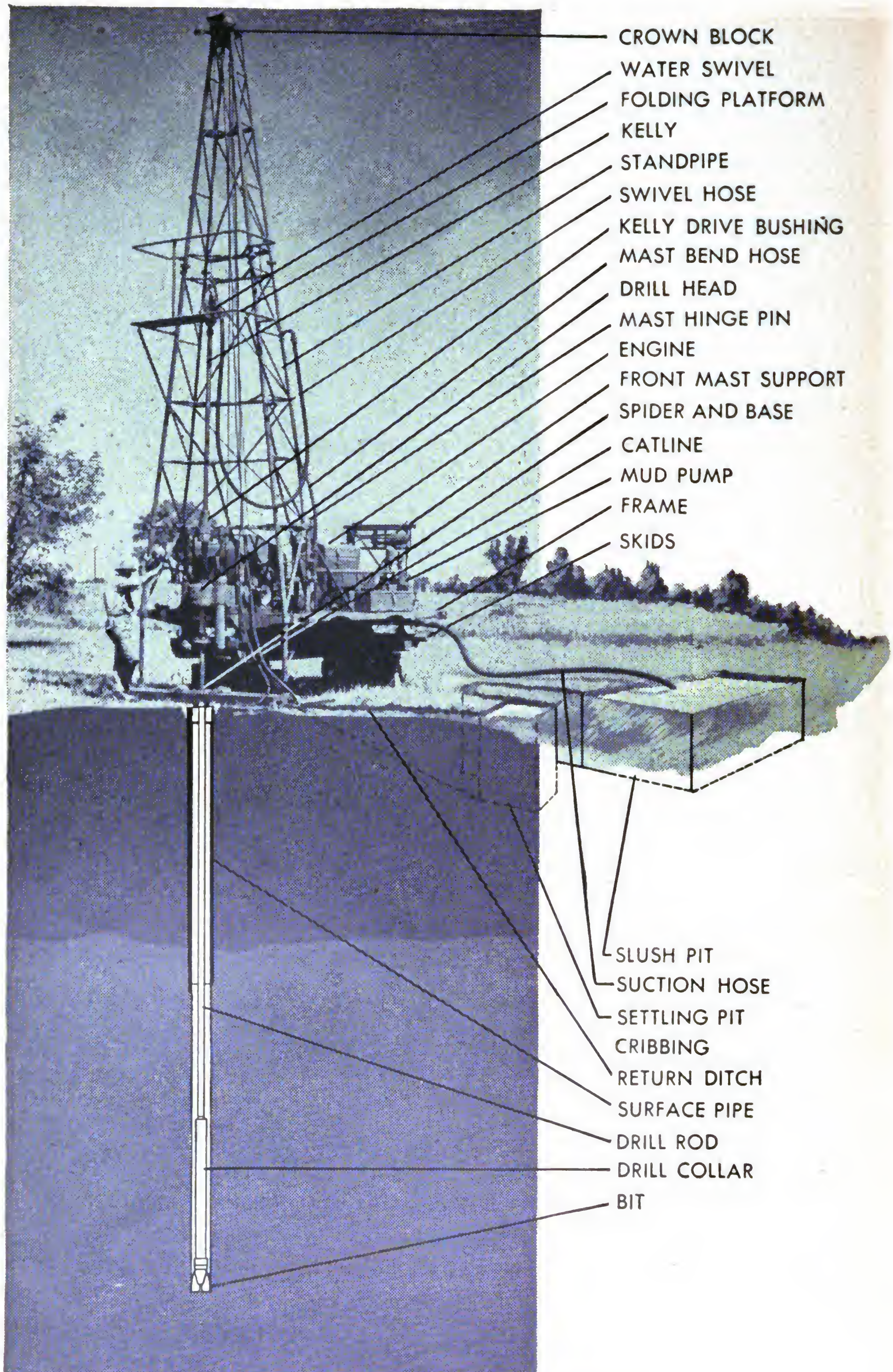


FIGURE 22. *Rotary method of drilling.*

gears. The speed of rotation is regulated according to the type, form, and size of bit, the formation to be drilled, and the strength of the drill pipe.

b. A swivel attached to the top of the kelly allows the drill pipe and bit to rotate with the driving mechanism while the upper part of the swivel remains stationary. The swivel and drill pipe may be raised and lowered by a steel cable which runs from the swivel over a sheave at the top of the mast or derrick down to a hoisting drum on the drill head. The hoisting drum and cable also control the weight and the rate of feed applied to the bit. These factors must be adjusted for penetrating the formations at the highest rate consistent with protection of the cutting edge of the tool from undue wear, drilling a straight hole, and the torsional and fatigue limits of the drill pipe.

c. **(1)** The drill pipe and swivel are hollow, to allow fluid to be pumped down through them to the bit. The fluid circulates through the drill pipe and out through holes in the bit, where it sweeps under the bit, picks up the material loosened by it, and carries it to the surface through the space between the drill pipe and the walls of the well. Fluid from the well overflows into a ditch and passes into a settling pit, where the cuttings settle. The fluid, free from coarse material and containing only fine-grained clay in suspension, flows into another pit and is picked up by the pump for recirculation in the well. Thus only enough fluid need be added to compensate for absorption by the formations penetrated, and for loss from the pits.

(2) Enough mud-laden fluid must be circulated both to clean the cutting tool properly and to rise in the hole fast enough to carry the cuttings with it. The fluid's weight and viscosity, aided by the plastering action of the drill pipe, must prevent the wall of the hole from caving. Its consistency must permit the cuttings to be held in suspension in the hole, yet permit them to settle out in the surface pits. If local mud is not satisfactory for the purpose, a commercially prepared mud must be added.

(3) Rotary drilling rigs range from small, light, and compact units to those able to penetrate to depths of many thousand feet. The type of power used depends upon the location and the type of well. Compressed air, steam, electricity, or internal combustion engines may be used. Regardless of size, however, the same principles apply to all rigs.

SECTION II

DESCRIPTION OF ARMY MACHINE

34. GENERAL. The Failing, model 314, rotary well drill, which has been adopted for Army use, is a completely portable rig for drilling small-diameter wells to a maximum depth of 1,000 feet. The unit consists of a gasoline engine power unit; a retractable draw works or drill head with a hoisting mechanism, rotating drive, and hydraulic-feed mechanism; a slush pump; and a folding tubular mast—all mounted on a structural-steel frame. All controls (fig. 23) are located at the left rear side within easy reach of the operator. Refer to TM 5–2024 for maintenance instructions.

The entire outfit can be bolted to skids (fig. 24), mounted on a truck (fig. 25), or trailer (fig. 26) with or without skids.

35. FRAME.

a. The drill frame is the foundation for all the units making up the drill. It consists of two 4-inch channel-iron sills crossed by 4-inch channel and I-beam members, and spaced at a width corresponding to the frame of an Army 4-ton, 6×6 truck with a 172-inch wheel base. The sills are interbraced with angle- and structural-shaped members located for maximum strength with minimum weight, electrically welded together. Upon this structure is welded and bolted a nonskid deck plate. Holes are drilled in the channel-iron sills so the frame can be bolted to the truck frame or skids.

b. The skids are two 10-inch wide-flange I-beams with the web cut out at the ends and the bottom flange turned up, giving them a runner effect. Five-inch channel irons are welded across the runners, between which pipe is welded for bracing. The runners are provided with a pipe cross member and pull hooks on the front, and rings for pulling or lifting on the rear. The channel-iron cross members are drilled to match the holes in the drill frame, so they can be bolted together.

36. POWER UNIT.

a. The power unit is a Buda, model HP–217, water-cooled gasoline engine, with magneto ignition. Its maximum governed speed is 1,600 revolutions per minute, which may be controlled by a hand throttle. The engine is equipped with electric starter and generator. The starter button, ignition switch, and choke are at the operator's position at the rear of the drill.

b. The front end of the crankshaft has a special fan-drive pulley to transmit power to the mud pump and hydraulic oil pump. Power is transmitted from the engine to the drill head through a disk clutch and selective-speed transmission, bolted to the flywheel housing.

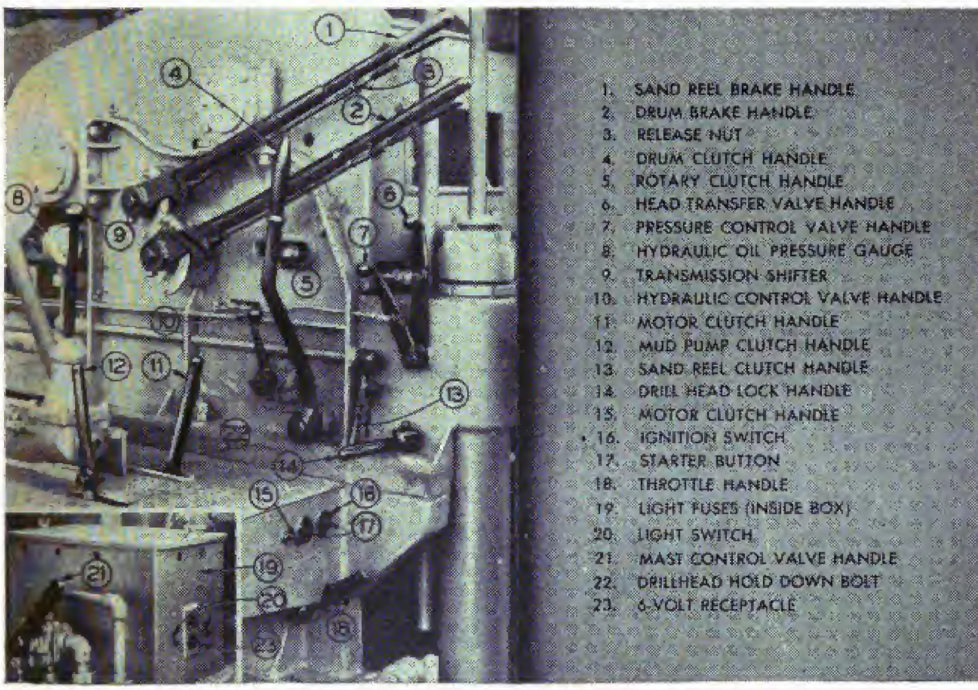


Figure 23. Location of operating controls on rotary drilling machine.

37. DRILL HEAD. The drill head consists of a rotating mechanism, a hoisting drum, a sand reel, hydraulic cylinders for applying added pressure or weight to the drill bit, and a hydraulic cylinder for moving the drill head to and from the drilling position. All these items, with their respective controls and driving mechanisms, are mounted on and within a cast-steel fabricated frame. All gears are in oiltight cases cast with the frame. All other moving parts are well guarded and are lubricated by pressure gun or oil reservoirs. Power is transmitted from the engine to the drill head by universal joints on each end of a splined telescoping shaft which connects the transmission to the drill-head power-input shaft.

by bearings in a yoke attached to the hydraulic-cylinder piston rods. To the upper end of this drive rod is screwed, with left-hand threads, a slip nut or kelly-drive nut, which has two notches for driving the kelly through the kelly-drive bushing. On the lower end of the drive rod is the chuck which screws onto the drive rod with right-hand threads. The chuck has two jaws to grip the kelly or drill pipe when applying pressure with the hydraulic cylinders. The jaws are actuated by screws on opposite sides of the chuck.

At 1,600 engine rpm, rotating speeds are:

First	38.2 rpm
Second	73.8 rpm
Third	146.6 rpm
Fourth	242.0 rpm

b. Hoisting mechanism. The hoisting mechanism consists of a hoisting drum, a sand reel, and a cathead, with their respective drives, lines, and fittings. The hoisting drum and sand reel are driven by a horizontal shaft running at right angles to the power-input shaft, which is turned by bevel gears. The cathead is keyed directly to the outer end of this shaft. The hoisting drum and sand reel are driven from this shaft by roller-chain drives. The following are the hoisting speeds of the main drum and sand line in feet per minute at 1,600 rpm:

First	61
Second	118
Third	235
Fourth	388

(1) Hoisting drum. The hoisting drum is engaged or connected to its drive by a friction clutch. The hoisting drum is used for pulling or running the drill pipe out of and into the hole, and for running and pulling casing. It has a brake at one end to control the rate at which the line can be unspooled. The brake is actuated by a lever on the left side. The hoisting drum usually is equipped with 80 feet of ½ inch wire line, at one end of which is a safety clevis for attaching the article to be hoisted. The main hoist has four speeds, with a maximum bare-drum line pull of approximately 18,000 pounds in first gear and 3,590 pounds in fourth gear.

(2) Sand reel. The sand reel is directly ahead of the hoisting drum. It is engaged by a sliding-jaw clutch which connects with the engine clutch. Its brake is actuated by a lever on the left side of the drill head. The sand reel generally is used to swab or bail the hole, but also may be used for other hoisting purposes. The sand reel is equipped with 1,000 feet of ⅜-inch wire line to which is attached a rope socket that connects to a safety clevis, the swab, or the bailer.

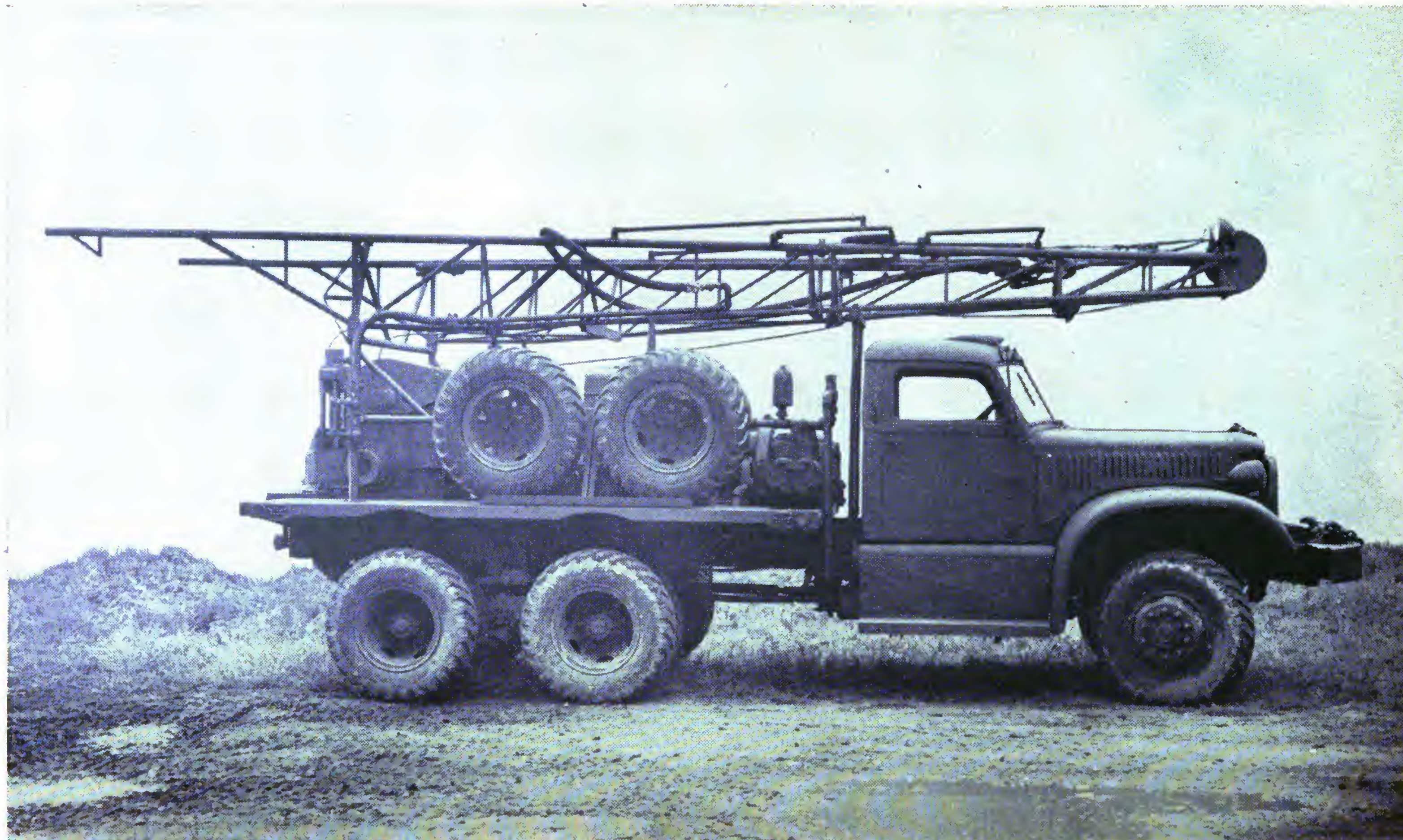


Figure 25. Rotary water-well drill, Failing model 314, mounted on a 6×6, 4-ton, 172-inch wheelbase Army truck with mast down in traveling position.

(3) Cathead. The cathead lifts light loads by wrapping a rope around the loads while the cathead is turning. The rope must be pre-

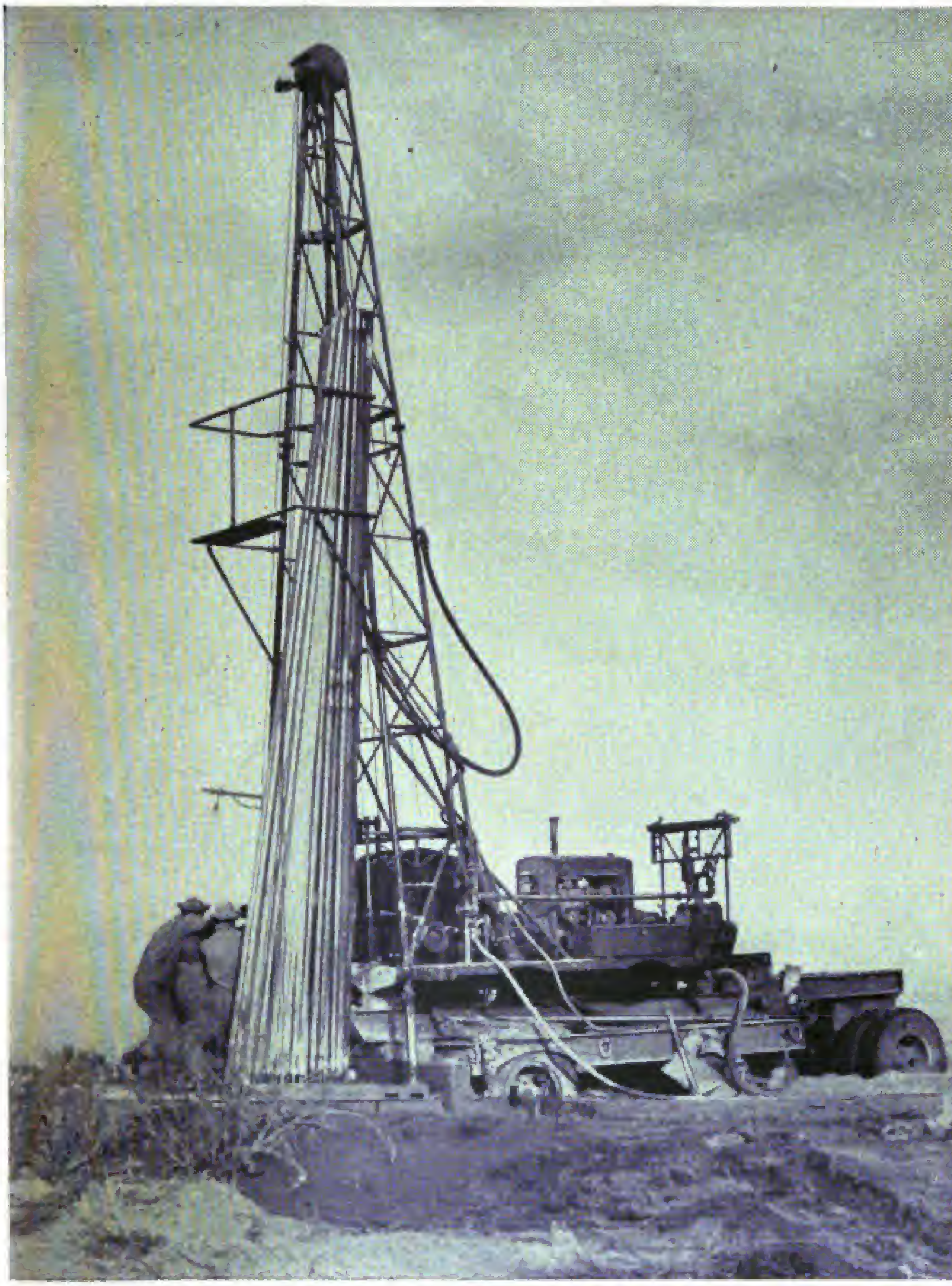


Figure 26. Rotary water-well drill, mounted on low-bed trailer.

vented from overlapping or becoming fouled. The cathead also is useful in driving or jarring pipe.

c. Hydraulic system. The hydraulic system consists of the following parts: two vertical cylinders connected to the drive rod through the hydraulic yoke and used to apply weight to the drill bit when needed, or to lift a horizontal cylinder to move the drill head to and from drilling position; two cylinders to raise and lower the mast; a pump to furnish pressure; an oil reservoir; and control valves for controlling each operation. All cylinders are double-acting.

(1) The vertical hydraulic cylinders are used when the weight of the drill pipe is not sufficient to make the bit penetrate the formations at the proper rate. The chuck bolts are tightened against the kelly or drill pipe when the chuck is in the highest position, and rotation is resumed. Sufficient pressure then is applied to the top of the hydraulic cylinders to make the bit cut. These cylinders also may be used to give a uniform rate of feed when drilling through shattered formations. When setting up the rig they are useful in raising the rear of the drilling unit to level it.

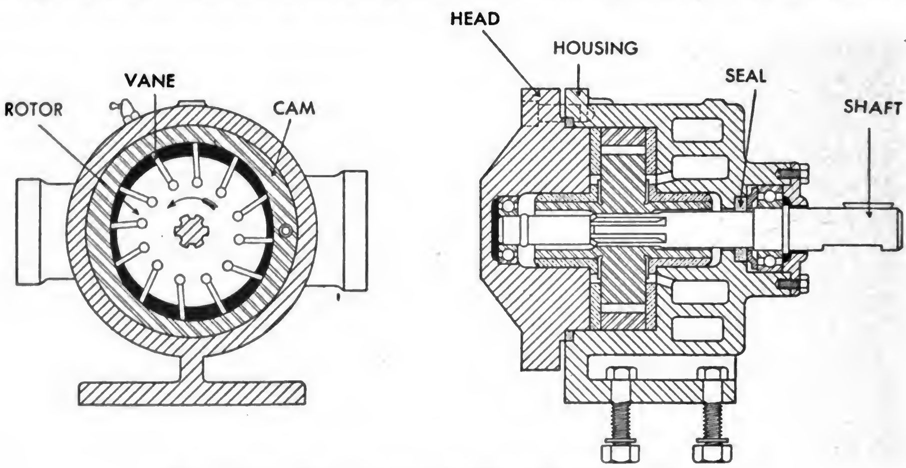


Figure 27. Cross-sectional view of hydraulic oil pump.

(2) Pressure for the cylinders is supplied by a vane type pump (fig. 27) driven from the front of the engine. The pump is mounted ahead of the engine and just below the deck. The oil reservoir is above the deck to the right of the engine. The system is protected from excessive pressures by a spring-loaded relief valve.

38. MAST.

a. The mast, or derrick, is built of steel tubing in two sections, bolted together with piloted flanges. It consists of four legs interbraced with tubular and structural-shaped cross members and diagonals, electrically welded. The rear legs have adjustable, removable jack extensions. It has three sheaves at the top (fig. 28) with oilite bearings. The sheaves run on a heat-treated spacer, held in place by a bolt. One sheave is for the catline or rope, one for the hoisting line, and one for the sand or bailing

line. The sheaves or crown pulleys have a hinged hood or cover. An anchor eye at the top is for anchoring the end of the hoisting line when a traveling block is being used. A folding platform and pipe rack are attached to the mast. The platform and safety rail fold down against the mast when it is in the lowered position (fig. 25).

b. The mast is attached to the drilling rig by a long bolt through hinge points on both of the front legs. Its gross capacity is 40,000 pounds. It is raised and lowered by two hydraulic-lift cylinders operated by a four-way control valve from the right side of the drill frame. (For instructions see TM 5–2024.)

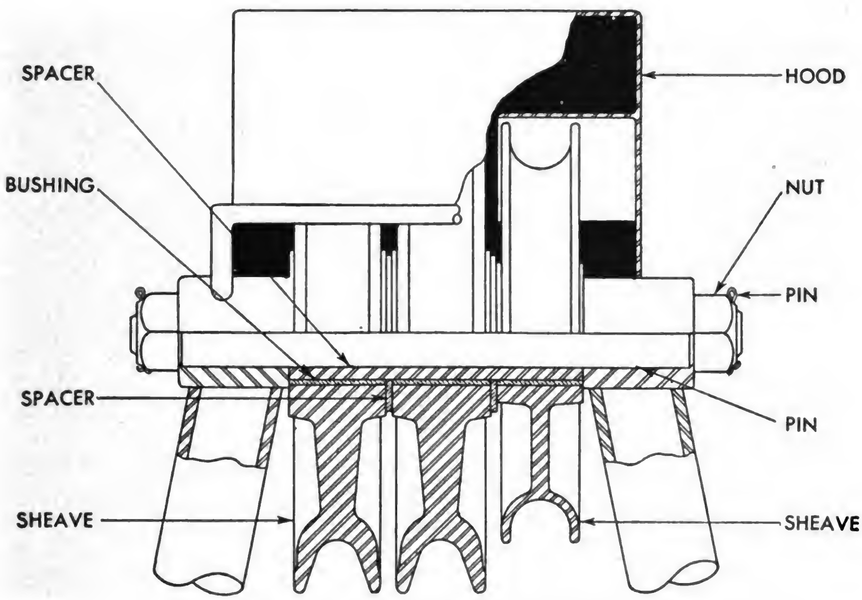


Figure 28. Mast head showing sheaves.

39. CIRCULATING SYSTEM.

a. In rotary drilling, continuous removal of material loosened by the bit prevents the accumulation of drill cuttings and "freezing" or sticking of the drill pipe. The mud pump is the heart of the circulating system.

b. The pump forces the mud-laden fluid through the discharge piping and the swivel hose, thence down through the swivel and drill pipe, and into the well just above the bottom, through holes in the bit. There it is deflected upward, and flows back to the surface between the drill pipe and the walls of the well, carrying the cuttings with it. It deposits small particles of clay on the wall of the well, sealing off porous formations and preventing loss of fluid and caving of the well walls. It also cools the bit and reduces friction between the drill pipe and the well walls. At the surface it flows through a ditch into a settling pit, where the coarser

and heavier particles settle out; it runs to the main pit, where it is picked up by the pump and recirculated. The pump (fig. 29) is a duplex, double-acting type, with removable, hardened-steel cylinder liners and rubber cup type pistons. It has renewable hardened valve seats, and wing-guided valves. The liners, pistons, and valves are the most vital units of the pump and are subjected to the greatest abuse and wear from abrasive material in the circulating fluid. They should be checked frequently to insure the most efficient and economical operation.

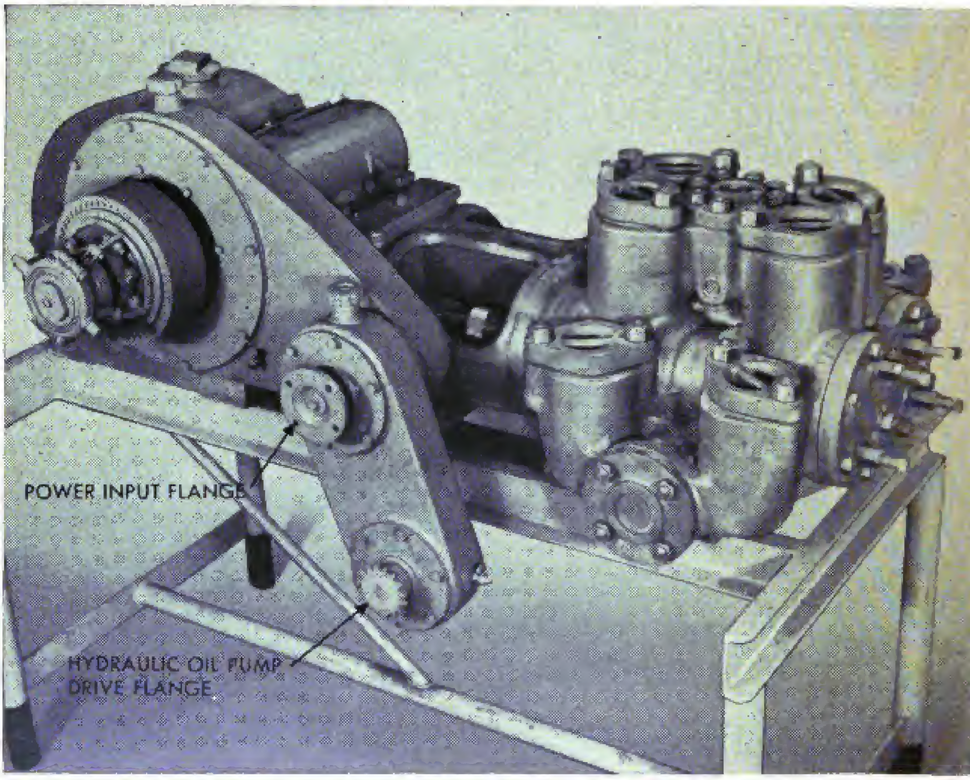


Figure 29. Mud pump with drive cases.

c. The size of the pits (fig. 22) varies with the size and depth of the hole. A receiving pit for a 6-inch hole 200 feet deep is at least 4 feet wide, 6 feet long and 2½ to 3 feet deep. The settling pit is at least 3 feet across and of about the same depth. The pits are so arranged that fluid flowing in and out of the settling pit is retarded or reversed, to give the cuttings more time to settle out. A wooden partition in the main pit also helps to settle the cuttings. Keeping the circulating fluid as clean and free from abrasives as possible adds life to pump parts. Larger particles remaining in the fluid retard drilling.

d. The suction hose, swivel hose, and circulating fluid are discussed in more detail in section III.

SECTION III

ACCESSORY EQUIPMENT

40. GENERAL. Accessory equipment varies according to the diameter of the hole and the purpose for which it is drilled. This section describes only those items of equipment furnished for or most likely to be used in drilling and developing water wells. All accessory equipment and tools are described in TM 5–2024.

41. SWIVEL. a. The swivel (fig. 30) is means for conducting the circulating fluid into the rotating drill pipe and for suspending the drill pipe in the well. It consists of a housing with trunnions, to which is fastened the supporting bail and a barrel-shaped rod that connects to the kelly and rotates in the housing on roller and ball thrust bearings. Sometimes a ball thrust bearing interchangeable with the roller bearing is used. A gooseneck and wash pipe are fastened to and supported by the upper bearing plate. A gland and packing prevent leaks between the stationary wash pipe and the rotating body. The housing is oiltight, and sealed against leakage. All moving parts except the upper ball bearing are lubricated by an oil bath. The swivel is filled with oil through the filler plug in the top plate. The upper ball bearing is lubricated by a pressure-gun fitting in the upper bearing plate.

Figure 30. Swivel.

b. The principal wearing parts are the wash pipe and packing. However, the bearings and seals wear excessively if not properly lubricated at regular intervals. Good performance from the swivel depends upon the packing and its adjustment. The packing gland should be tightened evenly, just enough to seat against the packing; otherwise the swivel does not operate freely, and the swivel hose tends to wrap around the kelly. If the gland is too tight it causes excessive wear on the packing and wash pipe.

42. KELLY. The kelly (fig. 31), sometimes called the "grief stem," is the uppermost joint of drill pipe, made from heavy-walled heat-treated tubing. It permits the drill pipe to be rotated by the drill and at the same time move vertically. It has three flutes or grooves, evenly spaced and running lengthwise to within a few inches of either end. The upper end has a left-hand thread and is connected to the body of the swivel with a sub. The lower end has a right-hand thread and is connected to a short joint of drill pipe with a coupling.

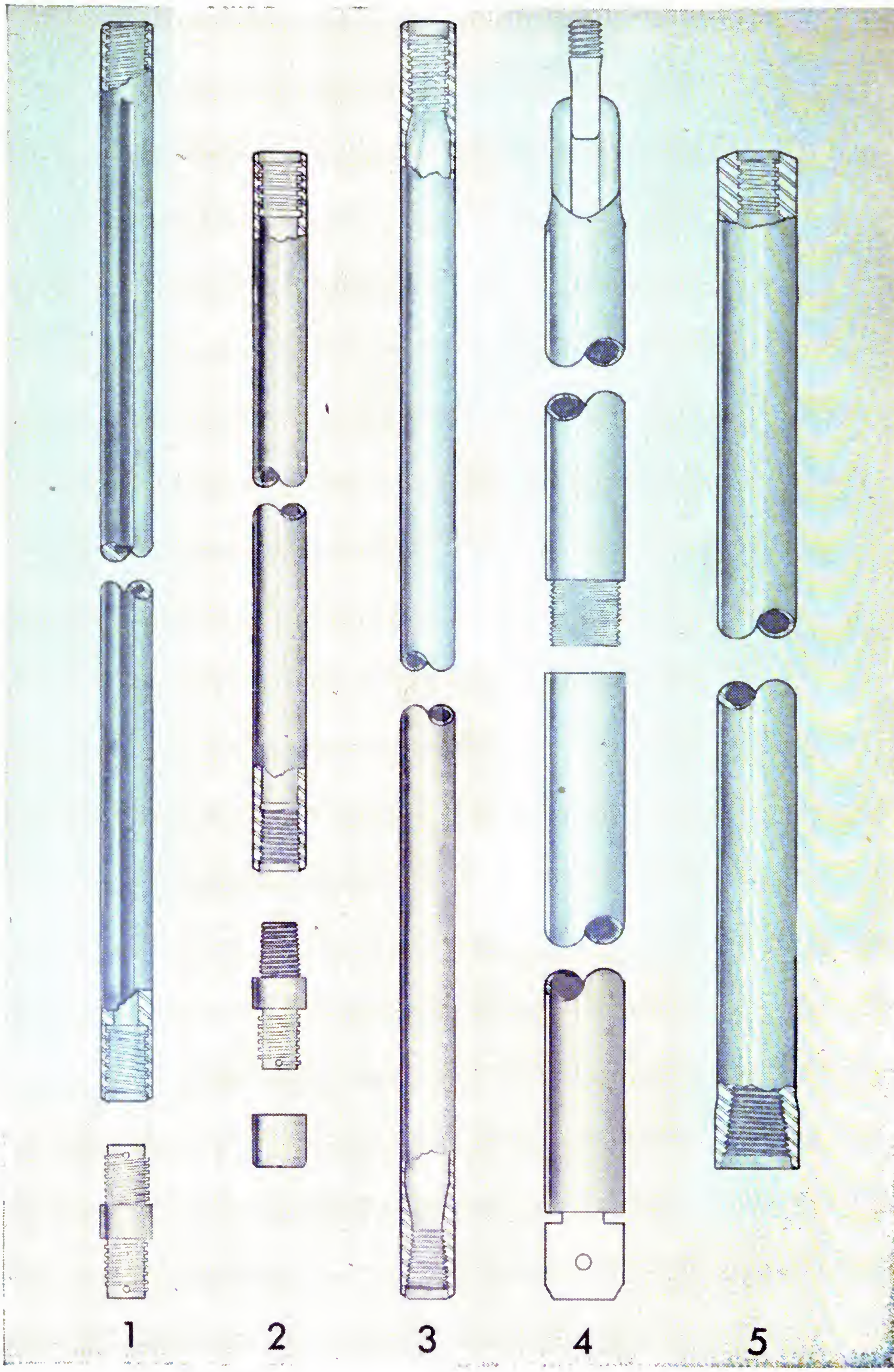
43. KELLY DRIVE BUSHING. The kelly drive bushing (fig. 32) is the connection or drive between the kelly and the drill. It is cylindrical, with two driving lugs on opposite sides. The inner bore is slightly larger than the outside diameter of the kelly and has three flutes spaced to match the ones in the kelly. Driving pins fit in these flutes and in those in the kelly, and are held in place by a top plate fastened to the drive bushing with four cap screws.

44. HOSE. Four hoses are used in the mud circulation system. Three are essential; the fourth is used for convenience.

a. Swivel hose. The swivel hose is 1¼ inches in inside diameter, and 17 feet long, and has wire reinforcements to withstand high pressure. It forms the flexible connection between the stand pipe and the swivel. It has hose nipples with 1¼-inch pipe threads and clamps on each end. The swivel hose is subjected not only to abrasive fluid under pressure but also to continuous flexing. Care is taken to eliminate short bends and kinks.

b. Stand-pipe hose. The stand-pipe hose is of the same size and construction as the swivel hose, but only 42 inches long. It has couplings of the same type. The stand furnishes a flexible joint so the mast can be raised and lowered.

c. Suction hose. The suction hose connects the mud pump and the slush pit. It is a 20-foot smooth-bore hose, reinforced with steel wire. This hose is coupled with band type hose clamps and hose nipples having 2½-inch male pipe threads. It is connected to the pump by a ground joint union. All clamps and pipe joints used in the suction line should be sufficiently tight to prevent air leaks. Impacts from heavy objects



1. *Kelly and sub.*
2. *Short drill rod, sub, and thread protector.*
3. *Drill rod.*
4. *Bailer.*
5. *Drill collar.*

Figure 31. Drill rod and drive equipment.

flatten the hose and pull the inner tube loose from the carcass. Even if the carcass is straightened on the outside, the pump suction may cause the inner tube to close and stop the flow of fluid.

d. Mud-mixing hose. The mud-mixing hose is a wire-wrapped, high-pressure, 1-inch hose, 25 feet long, much lighter than the swivel hose. It has hose nipples with 1-inch pipe thread and bolt clamps. A reducing nipple increases pressure and obtains a better mixing stream when needed.

45. SPIDER AND SLIPS. When the drill pipe is moved in or out of the hole the spider and slips are used to hold it while a joint is being removed or added.

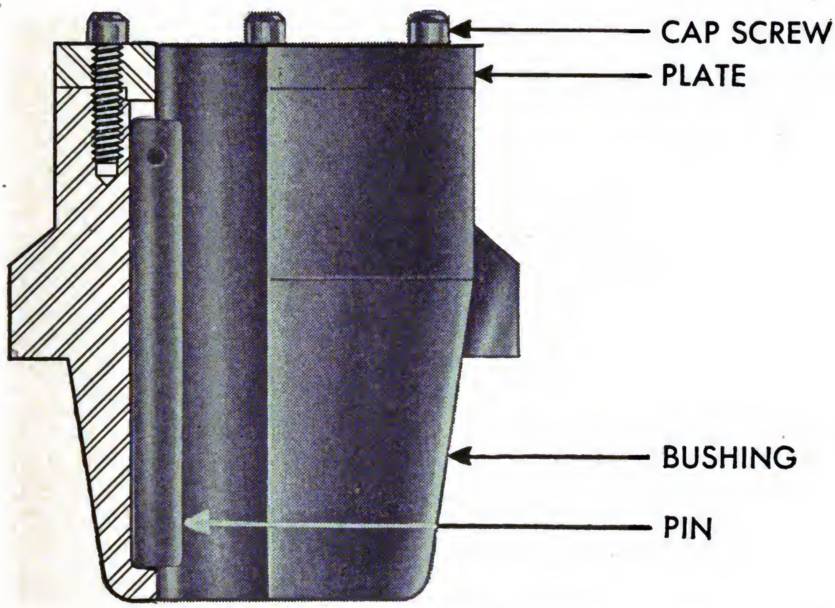


Figure 32. Kelly drive bushing.

a. Spider bowl. **(1)** The spider bowl (fig. 33) is a sleeve with a tapered bore large enough to allow the pipe to pass through, and a supporting flange on the outside. It is mounted on a channel-iron base floored with raised-design metal.

(2) A split ring (fig. 33) or bushing, tapered on the inside fits in the spider bowl. It is used when the drill rods or 3-inch pipe are run or pulled, to permit the use of lighter slips.

b. Slips. The slips (fig. 33) are circular wedges made in four pieces and fastened together with handles in sets or pairs. They are heat-treated to insure longer life and a better grip on the pipe. Each pair of slips is made for pipe of a certain diameter. The inside bore has teeth or threads which fit the outside of the pipe; the outside is tapered to correspond with the taper in the spider bowl or split bushing. When the slips

are set around the drill rods or pipe, the teeth grip it and pull the slips down in the tapered bore of the spider, which in turn causes the slips to tighten against and hold the pipe. Slips for the drill rods and the 3-inch casing work inside the split bushing; slips for 4-inch, 5-inch, and 6-inch pipe work in the spider bowl without the split bushing.

46. HOISTING PLUG. The hoisting plug (fig. 34) is the connecting link between the hoisting line and the drill pipe. It also is used with a casing plug or adapter to run or pull casing. It consists of a bail, a roller bearing, and a coupling like that used in the bottom of the kelly. The hoisting plug should be kept clean and the bearing and coupling threads are oiled to insure smoother spinning.

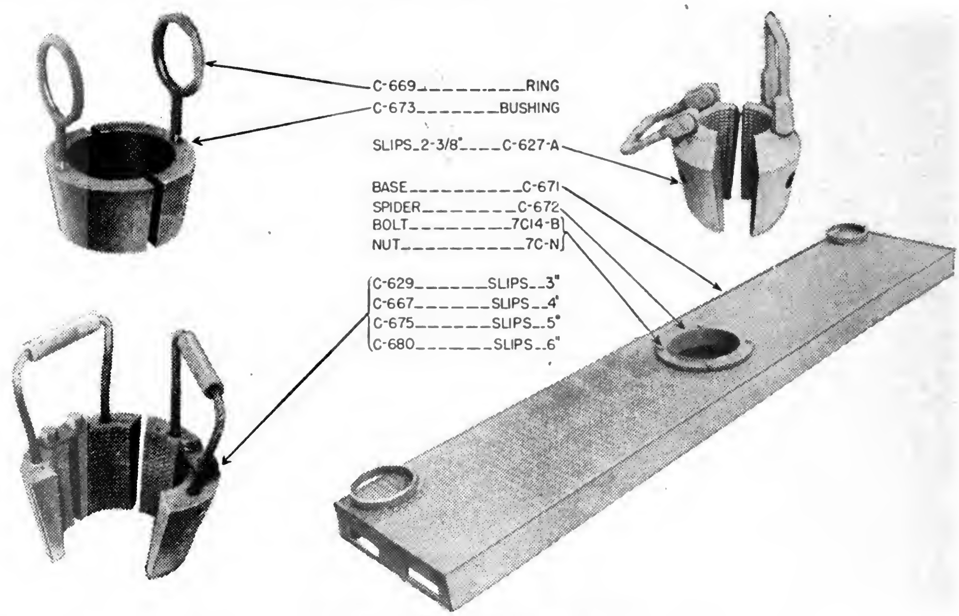


Figure 33. Spider and slips.

47. DRILL PIPE.

a. The drill pipe is capable of considerable elastic deformation between the drive rod at the surface and the bit at the bottom of the hole ((2) and (3), fig. 31). The amount of twisting and torsional strain varies with the bit pressure applied, the length of the drill pipe, and the resistance offered to the bit by the formation. Under extreme conditions the drill pipe probably assumes a corkscrewlike position in the hole. It revolves with a rapid variation in stress as the bit alternately digs into the formation and breaks free.

b. The stresses developed occasionally are sufficient to cause failure or twist-off of the drill pipe. Such failures usually are at the point of maximum bending and compressional stress. High-speed rotation, large hole size, and metal fatigue cause failures or twist-offs which often cause lengthy and costly fishing jobs.

c. Drill pipe is made in many sizes and lengths with various types of joints or couplings. The drill pipe in use on the Army rotary well-drilling rigs is external flush. It is made of a special seamless tubing, upset or swedged back on the inside of each end to give sufficient wall thickness for the turning of the threads. One end has a tapered V-type thread in which is bucked the special coupling or sub. The other end has a box turned with a modified acme thread cut three threads per inch. The exposed end of the coupling is threaded to fit the box end. Each joint is 2⅜ inches outside diameter, and 10 feet long. The coupling has a 1⅛ inch bore.

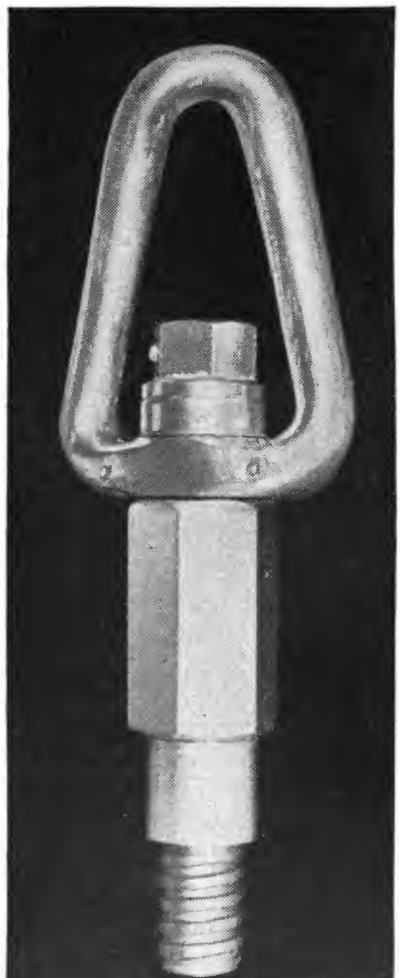
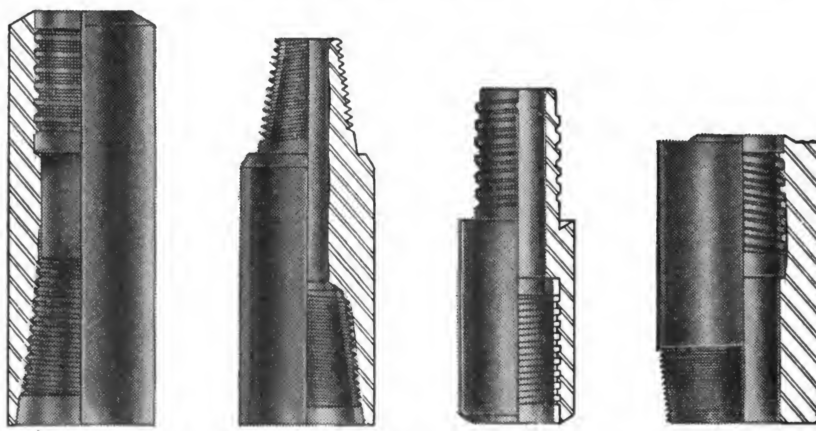


Figure 34. Hoisting plug.

d. As the drill rods are subjected to great torsional strains as well as wear, the threads of each joint are thoroughly cleaned, greased, and wicked before running in the hole. At the same time, each joint is examined for cracks and wear. If a joint is cracked or badly worn, it is discarded.

e. The wicking is used to seal against leakage and to keep joints from becoming too tight. It is a six-strand cotton yarn, issued in balls. For use, wicking is cut in 8-inch lengths and separated into pieces having two or three strands. The pieces then are twisted tightly together and tied around the coupling pin just below the shoulder. No wicking must get in the threads.

48. DRILL COLLAR. The drill collar ((4), fig. 31) is a joint between the bit and drill rods to stabilize the bit and help keep the hole uniform and straight. It is 10 feet long and has a diameter larger than that of the drill rods but small enough to clear the wall of the hole. In the top is an acme thread box which matches that of the drill pipe. The lower end of the 3½-inch outside diameter drill collar has a 2⅞-inch American Petroleum Institute box, and the lower end of the 4½-inch outside diam-



1. Drill rod box to American Petroleum Institute box.
2. American Petroleum Institute pin to American Petroleum Institute box.
3. Left-hand box to drilling pin, used to connect swivel to drill rods.
4. Casing plug drill box to pipe thread.

Figure 35. Sectional view of subs.

eter drill collar has a 3½-inch American Petroleum Institute box. The 6⅝-inch outside diameter drill collar has an American Petroleum Institute pin on the upper end and a 3½-inch American Petroleum Institute box on the bottom. It is run on the bottom of one of the smaller drill collars.

49. SUBS. A sub is a connection or adapter to connect drill pipe and bit, or drill collar and bit, when their threads are unlike. For some bits, two subs are necessary. Some subs have a box connection on both ends, while others have a pin connection on one end and a box on the other. Threads on subs are cleaned and well greased before they are used and tightened before they are run into the hole. Subs are illustrated in figure 35.

50. BITS.

a. At the lower end of the drill pipe is the bit which does the actual boring or cutting into the formations. The choice of bits depends on the individual preference of the operator and the nature of the formations to be drilled. A bit with a thin edge, or a number of slender prongs, is forced further into the formation with less pressure than one with a broad, flat surface.

b. Initial pressure is applied on the bit by the weight of the column of drill rods, aided by the hydraulic feed. Having penetrated the formation, the rotating bit disintegrates it by shearing or cutting action. The penetration of the bit and its speed of rotation must not be so great as to create a stress in excess of the safe torsional strength of the drill rods.

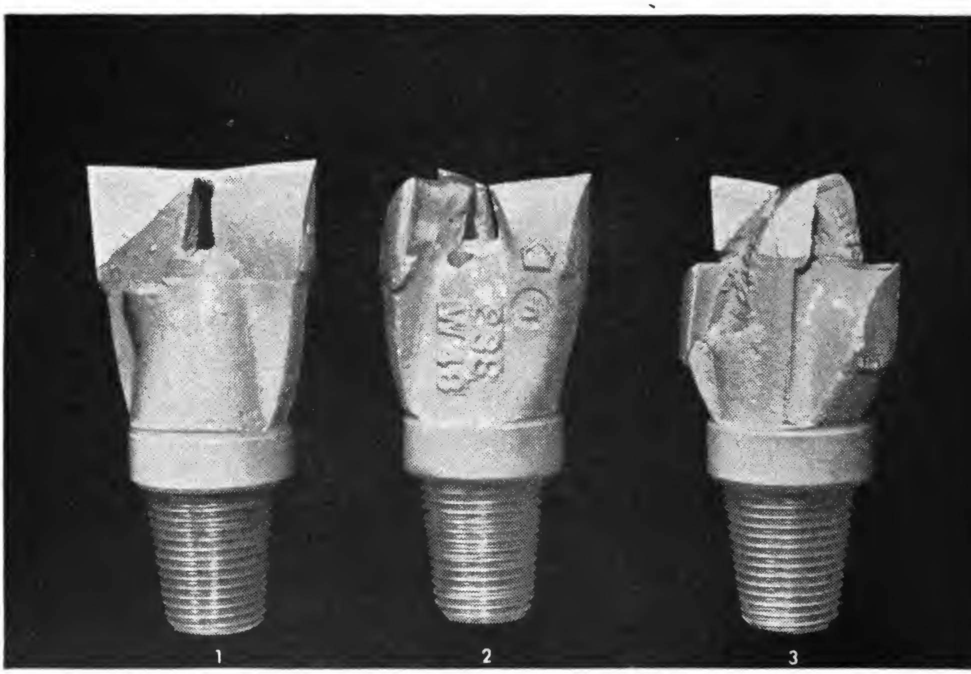
c. The bit also assists in mixing the cuttings with the circulating fluid. It must not cut the formation faster than the circulating fluid can carry the cuttings away. In this manual, only those bits furnished or likely to be used will be described.

d. The fishtail bit ((1), fig. 36) is made of steel, and the blades or wings are forged to a thin cutting edge turned slightly ahead. The cutting edges are faced with hard-surfaced metal and have tungsten carbide inserts in the outside corners. The body of the bit is hollow with a hole drilled on each side to direct the circulating fluid down near the center of each cutting edge. This fluid jets down the side of the cutting edges and keeps them clean. The fluid then is deflected upward by the bottom of the hole, carrying with it the material loosened by the bit. The fishtail is adapted especially to loose sands and clays. When harder formations are encountered, the bit is dulled rapidly and progress is slow. In semiconsolidated cemented sands, shattered formations, or formations containing loose boulders, it is not satisfactory because of the irregular torsional strain and vibration it imposes on the drill rods.

e. The three-way bit ((2), fig. 36) is much like the fishtail in design, but has three cutting blades instead of two. The three blades make its action much smoother in shattered or irregular formations. It also makes a better hole in semiconsolidated formations and has less tendency to be deflected. In soft formations it cuts a little slower than the fishtail.

f. The pilot bit (fig. (3), 36), sometimes called a six-way bit, is of the same general type as the fishtail and three-way bits. It has six cutting edges, each with a hole for circulating fluid. Three of these cutting blades cut a hole about half the diameter of that cut by the other three, and protrude down approximately 1½ to 2 inches below them. The two sets of blades are set at a 60° angle from each other. The pilot feature makes this bit better for shattered formations and cemented sands than either the fishtail or the three-way. It will cut somewhat harder formations, and with less irregular strain on the drill rods.

g. All the above bits have a shearing or scraping action, and so are not adapted to hard rocks. They can be resharpened with oxyacetylene welding equipment. For rotary drilling in hard formations, a more intricate bit is used. This bit depends upon a crushing and chipping action. The teeth of a rock bit are milled on the surfaces of cones or rollers which revolve as the bit is turned. A jet of the circulating fluid is directed from the inside of the bit to the top of each cone or roller. Rock bits cannot be successfully redressed. Two types of rock bit are in general use, each using the principle of disintegration of the formation.



1. Fishtail. *2. Three-way.* *3. Pilot.*
Figure 36. Bits.

Bits with cones or rollers having long teeth with wide spacing are best suited for soft formations. Harder formations require a bit having shorter teeth, more closely spaced, and not so long.

(1) Cone type rock bit. A cone type bit (fig. 37) has three cones, a forged-steel body, and a cone axle or pin which forms a part of the body. The cones have roller bearings fitted at the time of assembly. The cones are not removable. The three-cone construction provides smooth operation. The shape of the cutting surfaces and the design of the teeth in different types suit different formations. Some have interfitting or self-cleaning teeth. All cutting surfaces are flushed by the circulating fluid.

(2) Roller type rock bit. The roller rock bit (fig. 38) has four rollers or cutters and a steel body. Two cutters or rollers, on opposite sides of

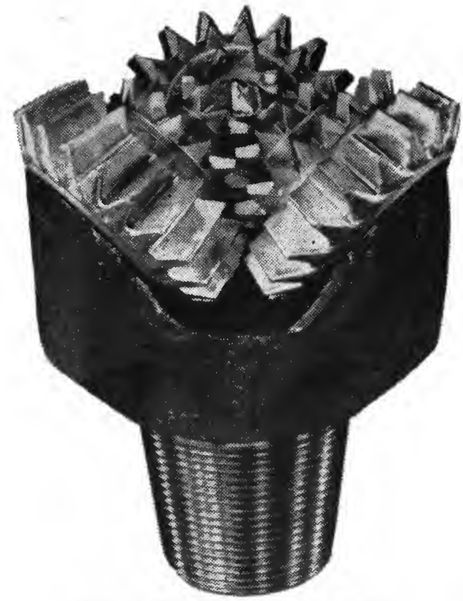


Figure 37. Cone type rock bit.

the body, are set at an inclination with the axis of the bit. These cut the outside clearance for the bit. The other two cutters or rollers are set in the housing at a 90° angle from the first two, and have horizontal axles. The latter cutters are somewhat conical in shape. The tooth design of the four cutters also is made to suit various formations. They are not renewable. The cutting surfaces are flushed by the circulating fluid. All cutters have roller bearings.

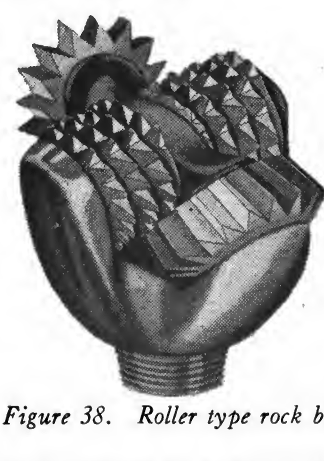
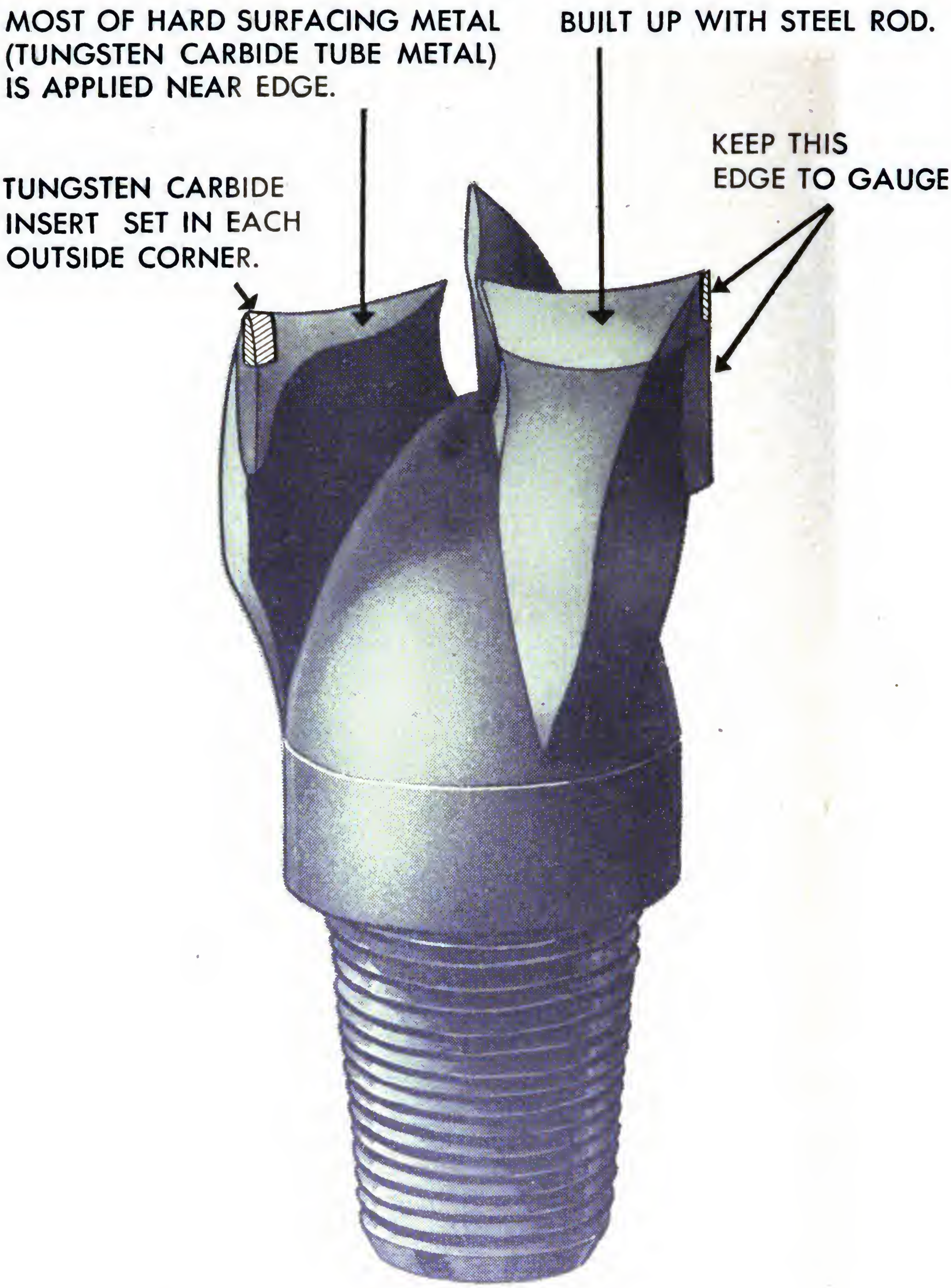


Figure 38. Roller type rock bit.

h. All the bits furnished except the 3⅝-inch fishtails and three-ways have American Petroleum Institute pin connections. The 3⅝-inch roller rock bits have 2⅞-inch American Petroleum Institute pins; and the 7- and 7⅞-inch bits have 3½-inch American Petroleum Institute pins. The 3⅝-inch fishtail and three-way bits have "N" acme boxes and screw onto the drill pipe.

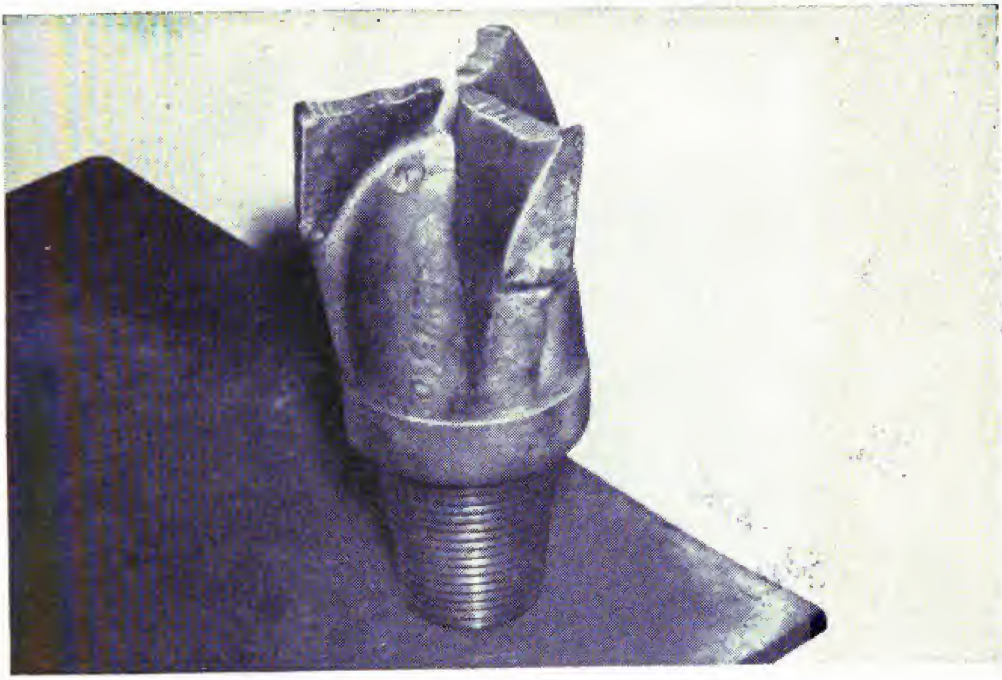
i. All types of rotary drag bits can be sharpened or redressed by a welder with an oxyacetylene welding torch, using steel and hard-surfacing



DETAILS APPLICABLE TO ALL TYPES OF DRAG BITS.

Figure 39. Bit-dressing diagram.

metal. See figure 39 for detail drawing and figure 40 for detailed instructions.



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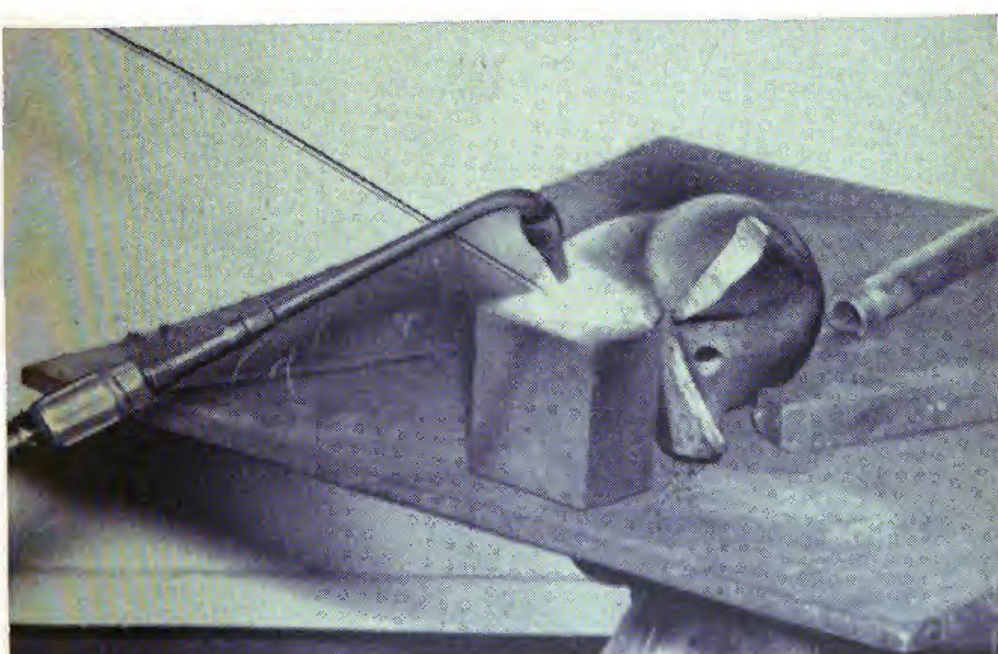

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Figure 40. Dressing bits.

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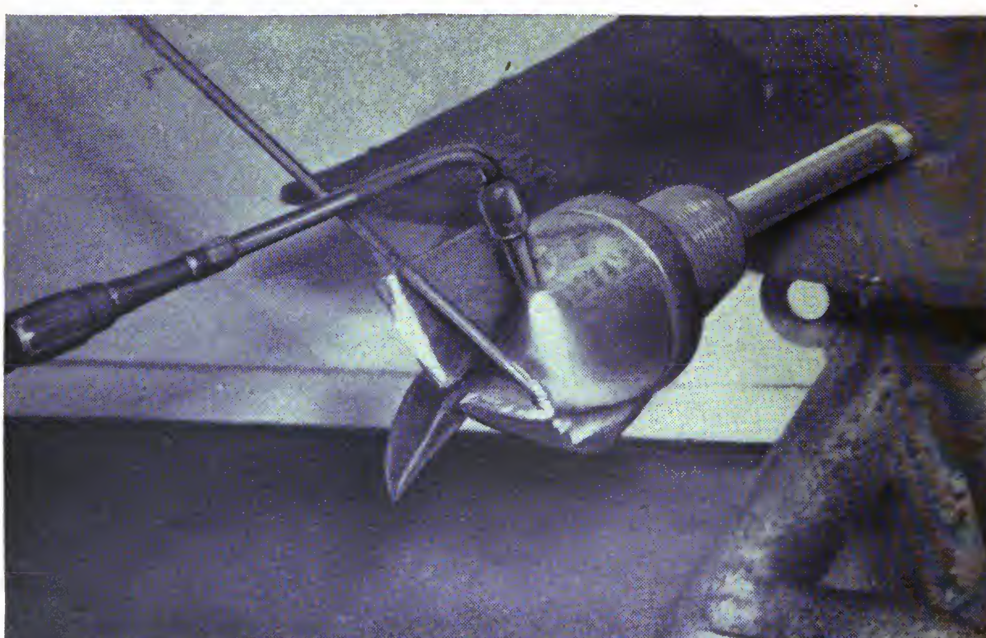

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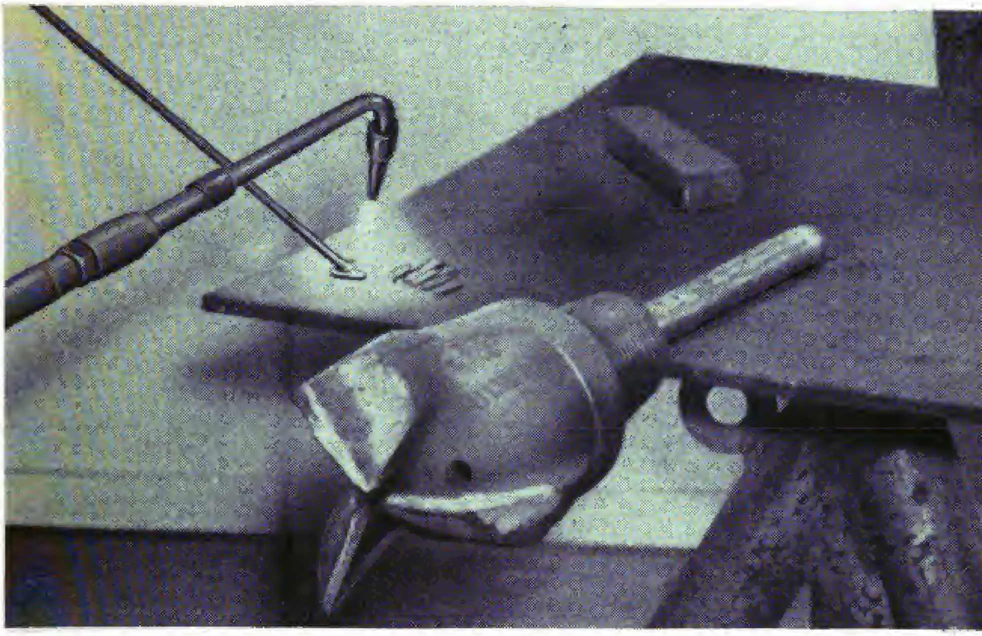
Figure 40. Dressing bits—Continued.



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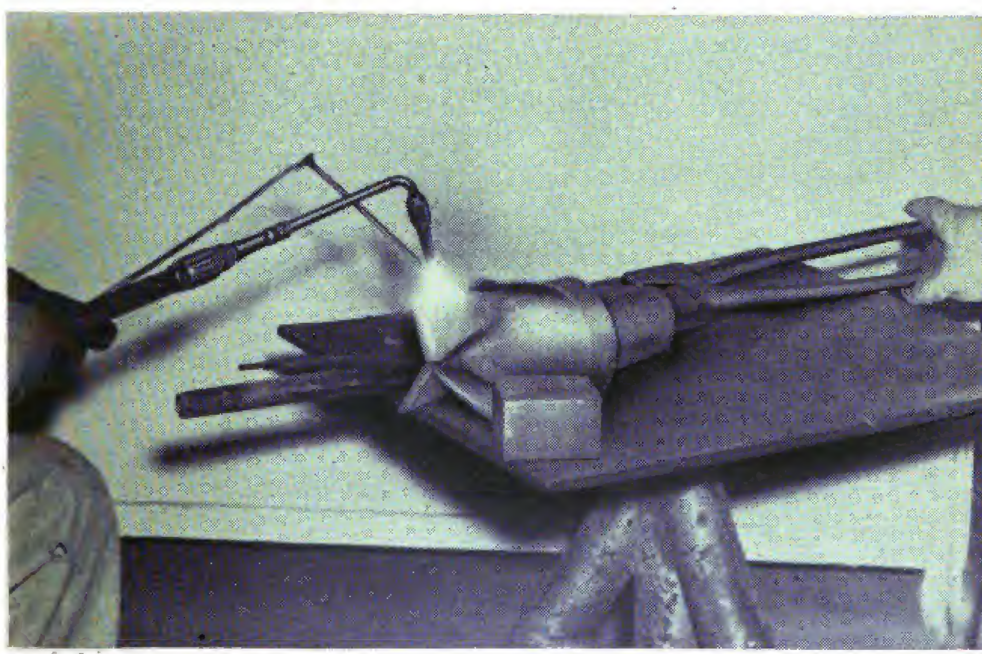

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Figure 40. Dressing bits—Continued.

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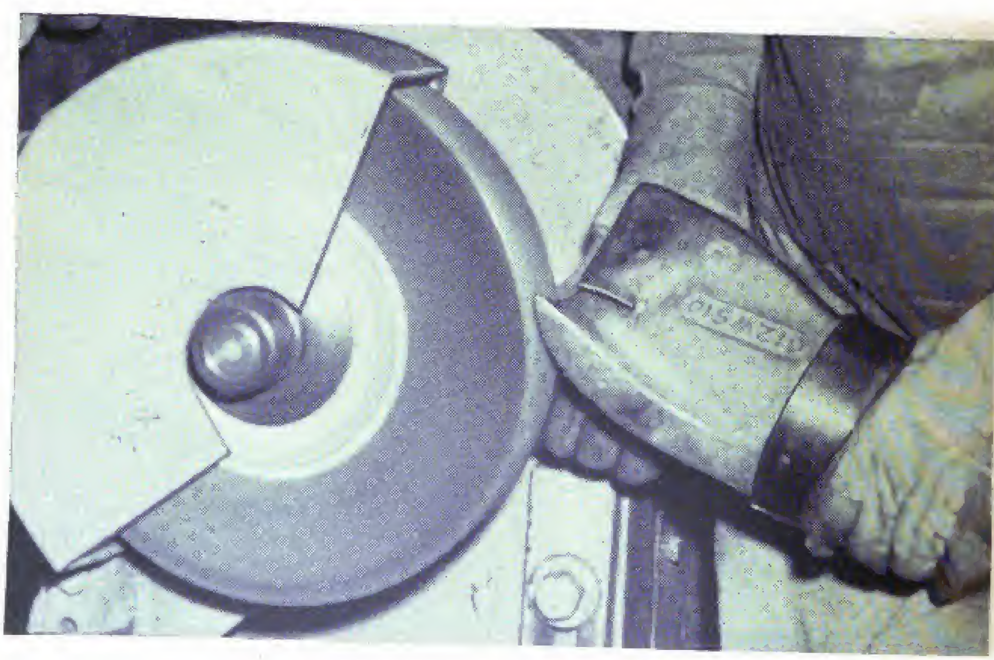

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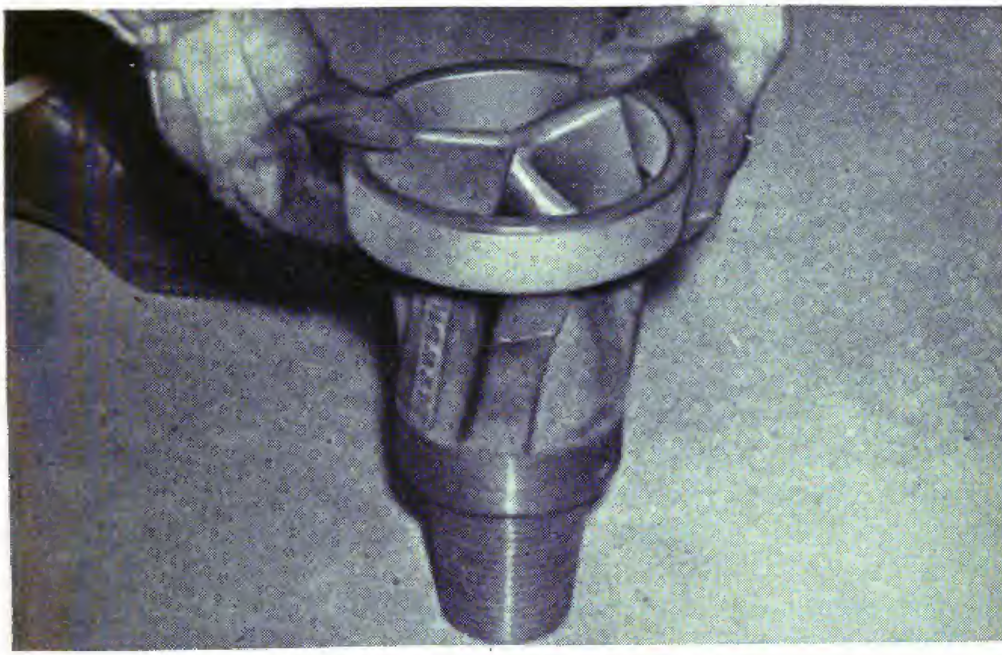
Figure 40. Dressing bits—Continued.



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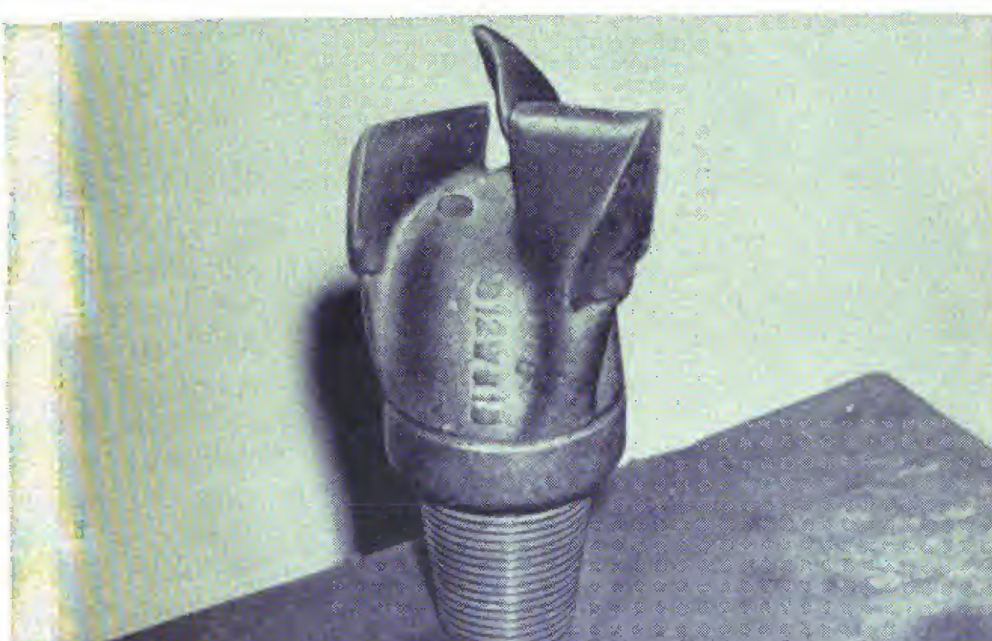

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Figure 40. Dressing bits—Continued.

51. FISHING TOOLS.

a. General. Fishing, the recovery of tools lost in the hole, requires a great deal of skill. The most frequent fishing job in rotary drilling is occasioned by twisting off of the drill pipe. The break may consist of a simple shearing of the pipe, or may occur at a coupling. Sometimes the drill pipe accidently is dropped into the hole. The first thing to remember when a break occurs is the exact depth of the break. This helps in locating the top of the tools and in coupling to it with a fishing tool. Many special tools have been devised to assist in fishing, but only the tools furnished with the Army rig are described below. The tapered tap and die overshot are simple tools, usually effective only if run immediately after the failure occurs. Recovery of lost drill rods depends upon whether the driller can set the tool down on the top of the rods and then connect to them. In wells in which the rods have become "frozen" from cuttings settling around them, and circulation to the bottom of the hole is required to loosen them, the circulating slip overshot is the best tool.

b. Tapered tap. The tapered fishing tap (fig.41) is tapered, approximately 1 inch per foot, from a diameter somewhat smaller than the inside diameter of the coupling to a diameter equal to the outside diameter of the drill rods. This tapered portion is threaded and is fluted the full

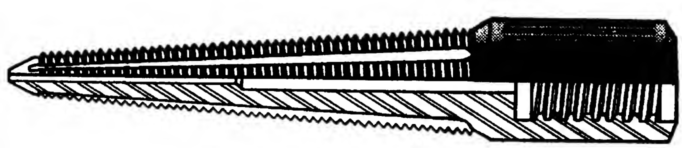


Figure 41. Tapered tap.

length of the taper. It is made of heat-treated steel. Its action is similar to that of a machine tap, as it cuts its own threads when rotated, and thus grips the lost drill rods. The flutes permit the escape of material cut by the threads. The upper end of the tap has a box threaded to fit the drill rods. There is a hole through the center of the tap.

c. Die overshot. The die overshot (fig. 42), sometimes called die coupling, is a long-tapered die of heat-treated steel. It tapers at the rate of 1 inch per foot from a diameter somewhat smaller than the outside diameter of the small end of the drill rod coupling to a diameter somewhat larger than the outside diameter of the drill rods. Like a machine die, it cuts its own thread as it is rotated on the lost drill rods. The taper thread is fluted to permit the escape of metal cut by the threads. The upper end has a box thread to fit the drill rods. The tool is hollow but, as is also true of the tapered tap, circulation cannot be completed to the bottom of the hole through the lost rods because the flutes allow the fluid to escape.

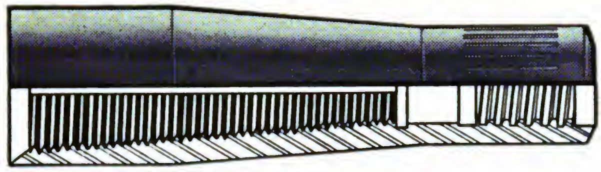


Figure 42. Die overshot.

d. Circulating-slip overshot. The circulating-slip overshot (fig. 43) is a tubular tool approximately 3 feet long, with inside diameter slightly larger than the outside diameter of the drill rods. The bottom is belled out, and has a notch to aid the tool to center and slip over the lost drill rods. The outside tube or body is of two pieces screwed together. The top of the lower section of the body is recessed to receive a rubber packer ring and a sleeve. The sleeve bore is tapered. On the inside of the sleeve is a ring-type slip whose bore is threaded with left-hand threads. This slip has a slot cut through one side so it can expand as the rods pass through it, and tighten against them as it is pulled down into the tapered sleeve. The body, sleeve, and slips are fastened together with lugs so they must rotate as a unit yet have a small amount of vertical movement independent of each other. The upper end of the top section of the body is threaded to fit the drill-rod coupling.

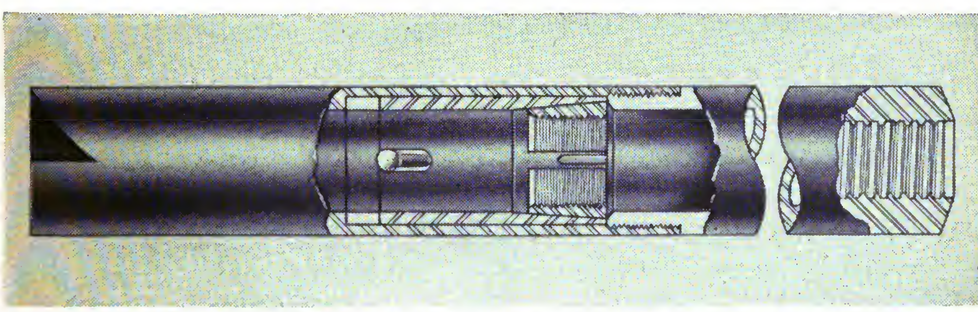


Figure 43. Circulating-slip overshot.

After the circulating-slip overshot has gone over the stuck drill rods and is pulled upward, the slips grip the pipe and the sleeve is pulled down against the rubber packer ring, which expands and makes a seal between the fishing tool and the drill rods. This assures the operator that, if circulation is completed, it is through the lost drill rods.

52. SWABS.

a. General. The well screen or strainer at the bottom of the well casing is usually clogged with mud when it is run into the hole. The surging action created by running a swab usually is successful in cleaning the screen and the pores in the walls of the well. The swab is similar to the piston in a cylinder pump. It consists of a mandrel on which are fastened

two rubber swabs or pistons. It also is provided with a means of bypassing the fluid as it is lowered into the well, and retaining the fluid on the upward stroke. The pistons should fit snugly but not tightly inside the casing. There are 3-inch and 4-inch swabs, exactly alike in principle and action, but somewhat different in design.

b. Three-inch swab. The 3-inch swab (fig. 44) is a valveless type, with rubber pistons made in two pieces. On the downstroke one-half of each piston slides upward, permitting the fluid to pass through. On the upstroke the movable half drops back into place and prevents the passage of fluid.

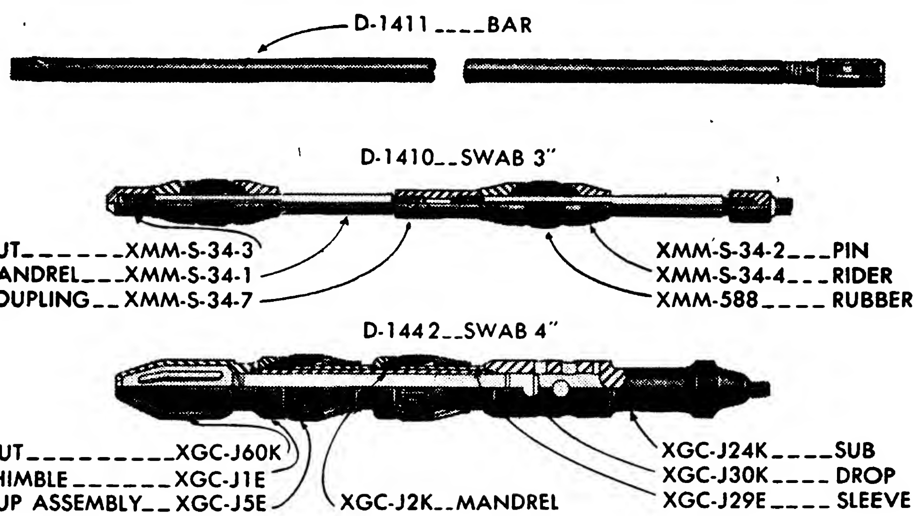


Figure 44. Swabs and sinker bar.

c. Four-inch swab. The mandrel of the 4-inch swab (fig. 44) is hollow, and is fitted with a ball valve. It has two rubber, cup type pistons inclosed in a flexible wire basket which protects the rubber cups in passing through pipe couplings. On the downstroke, the ball valve opens and allows the fluid to pass. On the upstroke, the valve closes and retains the fluid.

d. Sinker bar. To force the swab down in the well, weight is added by the sinker bar (fig. 44) a steel bar 1½ inches in outside diameter and 10 feet long. It has a box connection on one end that connects to the swab, and a connection on the other end to attach to the rope socket on the sand line. The same sinker bar fits both 3- and 4-inch swabs. The swab also provides a rapid means of removing fluid from the well after it has been developed. In deep wells with high-water levels, caution is required in lowering the swab so as not to lift a greater weight of water than the sand line will stand.

53. TRAVELING BLOCK.

a. The mechanical advantage necessary in handling safely a long string of pipe is gained through the hoisting or traveling block (fig. 45). This block has one sheave 12 inches in diameter, supported by heavy metal sides held together by three bolts. The sheave has a bronze bushing, and is lubricated by a pressure-gun fitting. To the bottom of a block is fastened a becket or bail, fastened to the sides by two of the bolts. The becket has a large, vertical hole through which is fastened a swiveling safety clevis.

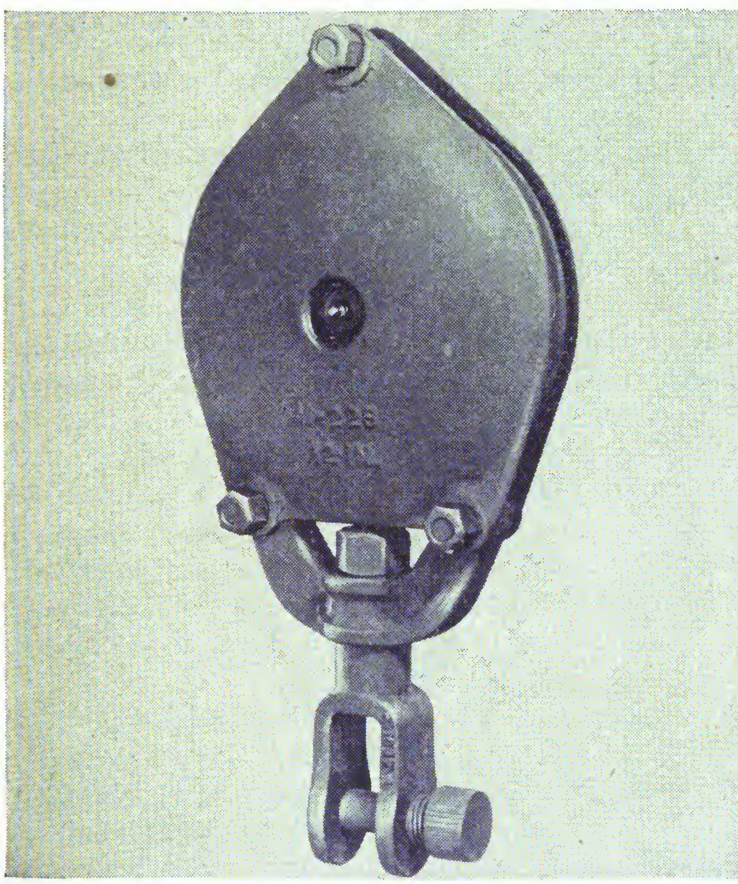


Figure 45. Traveling block.

b. This block is used to handle mote easily and safely 4-inch pipe or more than 600 feet of drill rods. The block is attached by removing the two bolts holding the becket to the sides, putting the line around the sheave, and replacing the bolts. The safety clevis on the end of the drum hoisting line then is fastened to the anchor eye at the top of the mast. The load is raised at half speed.

54. ELEVATORS. An elevator (fig. 75②) on a drilling rig is a device used in lifting pipe or casing. The simplest kind is a hinged clamp or ring with a quick-locking device to prevent it from opening when clamped around the pipe. On each side of the clamp or elevator is a lug or eye, to which is fastened the elevator bails or links. The bails are attached to the hoist. The bore of the elevator is slightly larger than the outside diameter of the pipe, permitting it to slip up against the coupling or collar when the pipe is suspended.

55. MUD.

a. A detailed discussion of mud or drilling fluid, as used in modern deep rotary drilling, is not within the scope of this manual. Only those problems most likely to arise, and the materials that will be available to Army operators, are considered.

b. In wells in which clay is near the surface, mud of sufficient viscosity and with some sealing qualities is formed by normal drilling operations starting with clear water. If the formations near the surface are sandy or porous it is necessary to mix mud before starting.

c. Aquagel, a prepared mud issued in powdered form in 100-pound bags, is furnished with each drilling rig. It is a gel-forming colloidal clay containing almost 100 percent colloidal material, and consequently free from abrasive particles. Mixed with water it makes a mud with practically all the qualities desired for shallow water-well drilling. It is possible to obtain 100 to 120 barrels of good mud from 1 ton of Aquagel; most ordinary clays make only about 20 barrels of mud per ton. As a suspending agent Aquagel is highly satisfactory in small concentrations. By depositing an impervious film of gel on the walls of the hole, it prevents loss of circulation. Even in porous or fractured formations complete loss of circulation generally is checked by its use.

d. Where porous or sandy formations are met and Aquagel or some other prepared mud is not available, it is necessary to find native clay for use in mixing the drilling fluid. Native clays are used for drilling purposes in emergencies, but are inferior. Most of them contain only a relatively small amount of colloidal material, and have a relatively large amount of sand that contributes little to the necessary properties of the mud. Consequently, these muds do not wall off the hole properly; large amounts of water are allowed to pass into the formation, while a thick filter cake is deposited on the walls of the hole. The intruded water promotes caving by hydrous disintegration, and has a tendency to reduce the permeability of productive horizons. The thick filter cake reduces the diameter of the open hole. This materially restricts the passage of tools and casing, and also promotes a swabbing effect that augments the tendency toward heaving when tools are withdrawn from the hole.

e. When a commercially prepared mud is added to native muds, an immediate improvement in performance takes place, as follows:

(1) A proper control of viscosity and yield point can be maintained, so cuttings are picked up and removed from the hole and then settle in the mud ditch.

(2) A thin filter cake is deposited on the wall of the open hole; this prevents the passage of water from the drilling mud into the formation.

(3) Loose, gravelly formations are consolidated, thus checking their tendency to cave or slough into the hole.

(4) When circulation temporarily is halted, all solids are held in suspension by the semiplastic gel which forms after agitation of the mud ceases. This gel is broken by resumption of drilling, and the cuttings are carried out of the hole.

(5) All moving parts of the drilling equipment coming in contact with the mud are covered by an adhering gel that acts as an effective lubricant and corrosion-resistant material.

f. In mixing either the prepared or native mud, use the mud pump and the mud-mixing hose with the reducing nozzle to obtain a high-pressure jetting stream. If the pits are dug in solid nonabrasive material the mud can be mixed in the pit by sprinkling a little of the Aquagel or clay in the water and mixing with the jetting stream. However, in a loose, sandy formation, use a box or steel drum for mixing the mud. This prevents mixing abrasive and noncolloidal material.

g. Various types of mud mixers are made, but for a small drilling unit a box about 2 feet wide, 4 feet long, and 1½ or 2 feet deep, with a hole about 6 inches square cut in one end and covered with a screen, is satisfactory. Set the box up with the hole end over the pit. Fill the pit with water, place a small quantity of mud in the box, and mix with the hose. As the mud is formed, it flows out through the screen and into the pit, where it circulates through the pump. Continue this operation until fluid of the desired viscosity is obtained.

h. When a barrel is used for mixing mud, clay is placed in the barrel and, with the bypass valve open, the main stand-pipe valve closed, and the suction hose strainer immersed in a supply of clear water, the mud pump is engaged with the clutch control lever and clear water is discharged into the barrel. Should the fluid contain lumps when the mixing barrel becomes full, mixing is continued by placing the suction hose in the barrel and circulating until the mud is mixed thoroughly. The pump clutch then is disengaged and the barrel of mud emptied into the slush pit. Additional mud is mixed, following the same procedure, until the slush pits are full. The bypass valve then is closed, the main stand-pipe valve is opened, and the mud is ready to be circulated in the hole.

56. WIRE LINE AND ATTACHMENTS. Wire line is manufactured in many designs and sizes. Only two designs and sizes are used on the Army model 314, rotary water-well drills.

a. Hoisting line. The hoisting line furnished is ½-inch nonrotating, usually about 80 feet long. It consists of 18 strands of 7 wires each, the 12 outer strands laid or twisted in one direction and the 6 inner strands in the opposite direction. This equalizes the rotating or twisting tendency present when all strands are laid in the same direction. This is desirable in a line used for hoisting purposes, where only a single or double line is used. To one end of the hoisting line is attached a safety clevis (fig. 46) for fastening the line to the swivel, hoisting plug, or other equipment to be lifted. The safety clevis is attached with babbitt metal or zinc as described in **d** below.

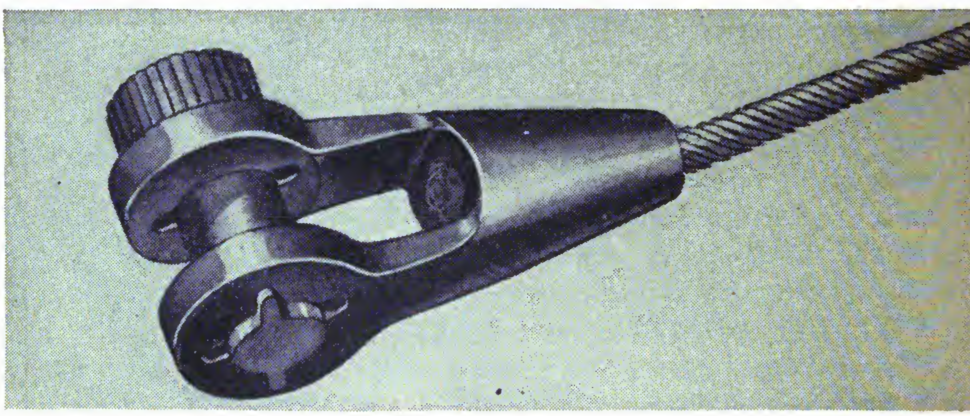


Figure 46. Safety clevis.

b. Sand line. The sand line is used for swabbing, bailing, and any hoisting within its capacity. It has a ⅜-inch outside diameter, and is 1,100 feet long. It has 6 strands of 19 wires each, twisted around a hemp center. Attached to its end is a rope socket (fig. 47) that connects the line to the bailer swab sinker bar, or a special safety clevis (fig. 47). The rope socket is fastened to the line with babbitt metal or zinc, as discussed in **d** below.

c. Care of wire line. Do not strike wire line with a hammer or other object. Keep the line tightly and evenly wound on winding drums. Above all, avoid kinks in a wire line. Keep it well lubricated with a good grade of noncorrosive wire-line lubricant. When it is to be out of service for any length of time, clean it carefully and then lubricate it.

d. Attaching safety clevis or rope socket. If a safety clevis or a rope socket is attached to a line, use the method described below and illustrated in figure 48.

(1) Measure from the end of the rope a distance equal to the length of

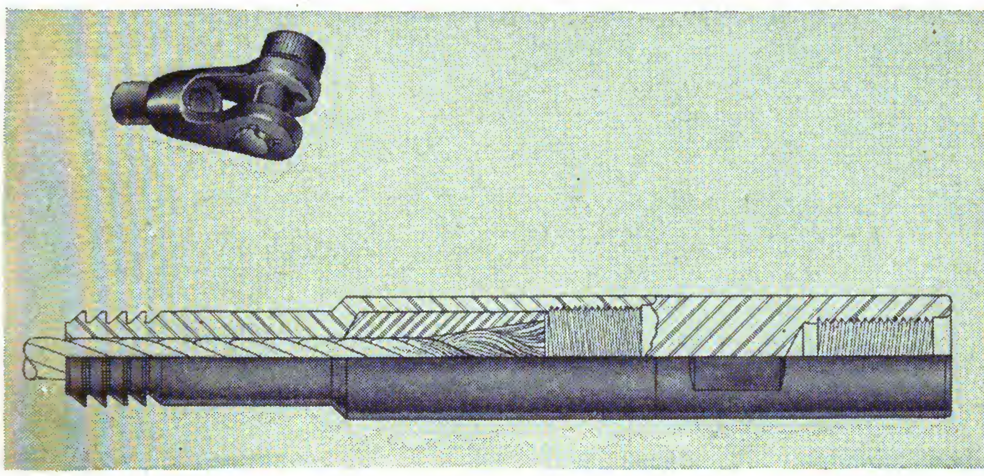


Figure 47. Swivel socket and safety clevis on sand line.

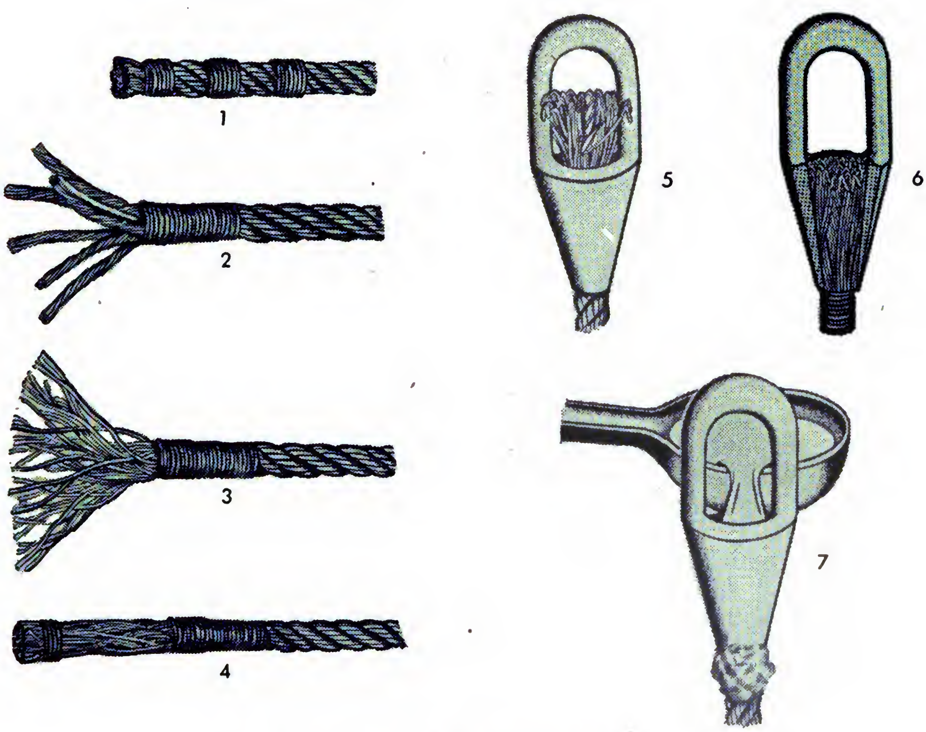


Figure 48. Attaching wire line.

the basket of the safety clevis or rope socket. At this point serve it with wire or seizing strand. It must be carefully applied and long enough to prevent the strands from untwisting, which would result in unequal tension on the strands when the clevis or socket is attached.

(2) Remove any seizing above that just mentioned. Cut off the hemp center at the seizing.

(3) Untwist the strands, and broom out the wires which are separated but not straightened. Carefully clean the wires with gasoline for the distance they are to be inserted into the socket. If available, dip the wires into a 50-percent solution of muriatic acid,just long enough to clean them thoroughly. Rinse with water and dry with a clean rag. Prevent acid from touching the rope below the seizing.

(4) Draw the ends together with a piece of seizing wire. Force the socket down over the rope end until it reaches the main seizing on the wire rope. Remove the seizing wire from the end, and allow the wires to expand within the rope basket. Seal the base of the socket with putty, clay, or similar substance.

(5) Heat the socket and wire slightly. Fill the basket with molten babbitt metal, or preferably zinc, until it is even with the top of the basket. When the babbitt metal or zinc has congealed, cool it in water and remove the seizing.

SECTION IV
OPERATION

57. CREW.

a. Success in well drilling depends largely upon the efficiency of the crew. The drilling rig and its controls are not complicated and can be mastered in a short time, but mere knowledge of mechanical operations is only the beginning. Experience is the vital element.

b. Adjustments in rotating speeds and bit pressures cannot be formulated into set rules. The same formation may require different drilling techniques in holes spaced only a short distance apart. A good driller knows from experience why each thing happens or why an operation is done in a certain way. He is able to visualize conditions at the bottom of the hole, and know the reaction of the bit in different formations. For example, a bit which becomes "balled up" when drilling in soft, sticky formations creates stresses and vibrations in the drill rods similar to those caused by drilling in shattered consolidated formations. A good driller can recognize formation changes and keep an accurate log of them. Experience is the only way to gain these qualifications. Drilling by an inexperienced operator is costly in both time and money.

c. Normal operations require a three-man crew, consisting of the driller and two helpers. The driller is in charge of all operations, and is responsible for the care and maintenance of the equipment. The helpers keep the settling pit cleaned, maintain an adequate water supply, keep fuel and water in the engine, and lubricate and service the equipment. When running the drill stem in or out of the hole, one helper works on the

ground and helps the driller break the joints. He sets the slips, screws the hoisting plug in and out, and helps set the drill rods in place. The other helper works on the mast platform. He screws or unscrews the hoisting plug and helps handle the drill rods.

58. RIGGING THE MACHINE.

a. A level site is required for drilling. After it is selected and the drill moved into position, the first operation is to level the drill (fig. 49). If it is on skids, it is necessary to set them on cribbing approximately 24 inches high. The rig is jacked or lifted up with a power winch on another vehicle and the cribbing placed about 2 feet from the ends of the skids. The cribbing is leveled and set on matting or on a firm foundation. If the unit is truck- or trailer-mounted it is leveled by digging holes for the wheels on the highest side or blocking up the low wheels. After the unit is leveled, raise the mast (fig. 50). Then place the spider base transversely under the rear of the unit, so the mast feet rest on the pads on the spider base. The spider base must be level and have sufficient blocking to withstand the load of pulling and supporting the drill pipe. Next take a slight tension on the hoisting line and tighten the brake. Then loosen the clamp holding the upper end of the kelly and remove the cap from the lower end. Pick up the kelly a few inches with the hoist and lower through the drive rod. The kelly is turned so the lugs on the drive bushing drop in the driving slots of the slip nut. Tighten the Allen setscrews. A bit now is attached to the kelly with the proper sub.

b. During this operation, part of the crew is digging the slush pit (fig. 50). The fluid-return ditch is dug from the hole to the settling pit and another from the settling pit to the main pit. The ditches enter and leave the settling pit in such a manner that the flow of fluid is reversed (fig. 22), causing the cuttings to settle and keeping them from flowing to the main pit. The pits then are filled with water and the suction-hose screen is placed in the main pit at the opposite end of the return ditch. The suction hose is submerged at all times, but does not lie on the bottom.

c. The circulating fluid is kept as clean and free from abrasives as possible, to protect the pump parts. The settling pit is kept clean during drilling to avoid loading the circulating fluid with cuttings.

d. The drill now is set up and ready for operation.

59. WATER SUPPLY.

a. A water supply is essential when drilling wells by the rotary method. There is no set rule as to the amount of water required to drill any one hole. In some cases, where the formations are compact, 3 to 4 gallons of water per foot of hole drilled are sufficient; but in other cases, where the

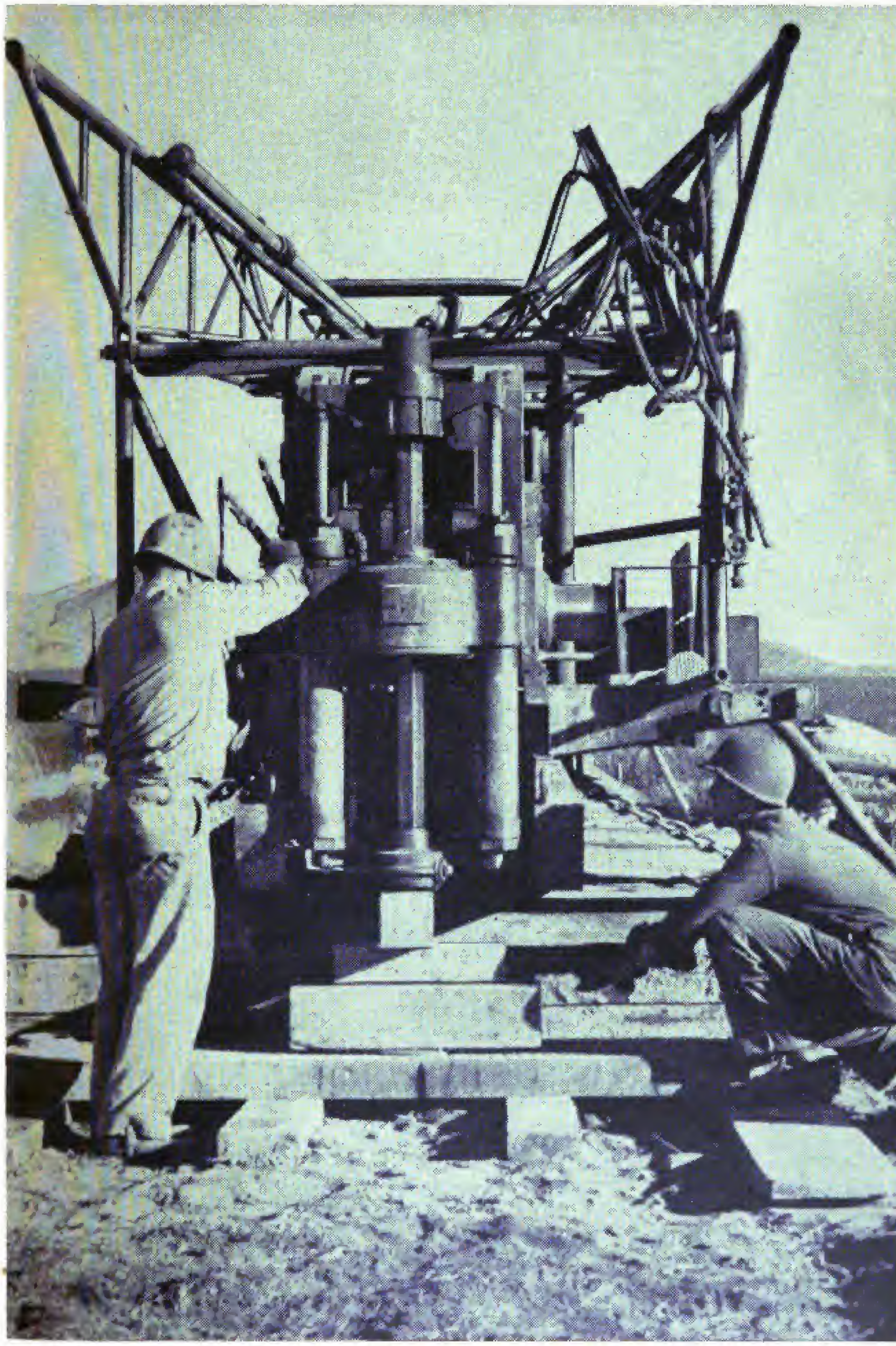


Figure 49. Placing cribbing under rear of rotary-drilling machine.

Figure 50. Raising the mast on rotary-drilling machine.

formations are loose and extremely porous, a large supply is required. For ordinary purposes 750 to 1,000 gallons of water per 8-hour shift is needed.

b. In tests conducted by the Desert Test Branch of the Engineer Board using the model 314 rotary-drilling machine, the amount of water required for drilling holes 4⅞ inches in diameter varied from 1.51 gallons to 16.88 gallons per foot of hole, the average being 6.65 gallons per foot. A 500-gallon skid-mounted water tank is furnished with each rotary drilling machine. Each machine also has a 3,000-gallon canvas tank for storage.

60. DRILLING.

a. Procedure. (1) Engage the mud pump, and when circulation has started, engage the rotation clutch and lower the bit by releasing the hoisting drum brake. In a soft formation, the weight of the kelly probably is sufficient to make the bit cut. If not, stop the rotation, tighten the chuck bolts, and resume rotation. Apply pressure to the bit by pulling back the hydraulic control valve and closing the pressure-control valve enough to make the bit cut. When the end of the hydraulic feed is reached, stop rotation, loosen the chuck bolts, and raise the chuck by reversing the hydraulic-control valve. This operation is repeated as long as added pressure is needed to make the bit cut.

(2) When the length of the kelly is drilled down, loosen the chuck bolts, hoist the kelly so the bit and subs can be removed, and disengage the mud-pump clutch. Pull the drill head away from the hole by pulling back the head transfer valve and closing the pressure relief valve. Screw the bit on the drill collar and lower it into the hole by either the catline or the hoisting line attached to the hoisting plug; set the slips in the spider around the drill collar. Next, move the drill head back to drilling position, lower the kelly carefully into the box of the drill collar, and rotate it slowly until the threads are tight. Before tightening, be sure there is wicking on the kelly coupling. Engage the pump clutch and hoist the kelly and drill collar until the slips can be removed; then lower to the bottom of the hole and resume operation.

(3) At intervals of 10 feet down this cycle of procedure is repeated except that instead of a drill collar (fig. 51) a joint of the drill rods is added each time. The catline may be used for lowering the drill rods into the hole, or pulling them, at depths not over 100 feet. If the hole is deeper than 100 feet,it is necessary to disengage the safety clevis from the kelly as the drill head is retracted, and to attach the safety clevis to the hoisting plug for handling the drill rods. Then reconnect the clevis to the swivel before the drill head is moved back to drilling position. If the formation is such that circulating fluid is lost by absorption in pores or crevices, mud is mixed before proceeding.

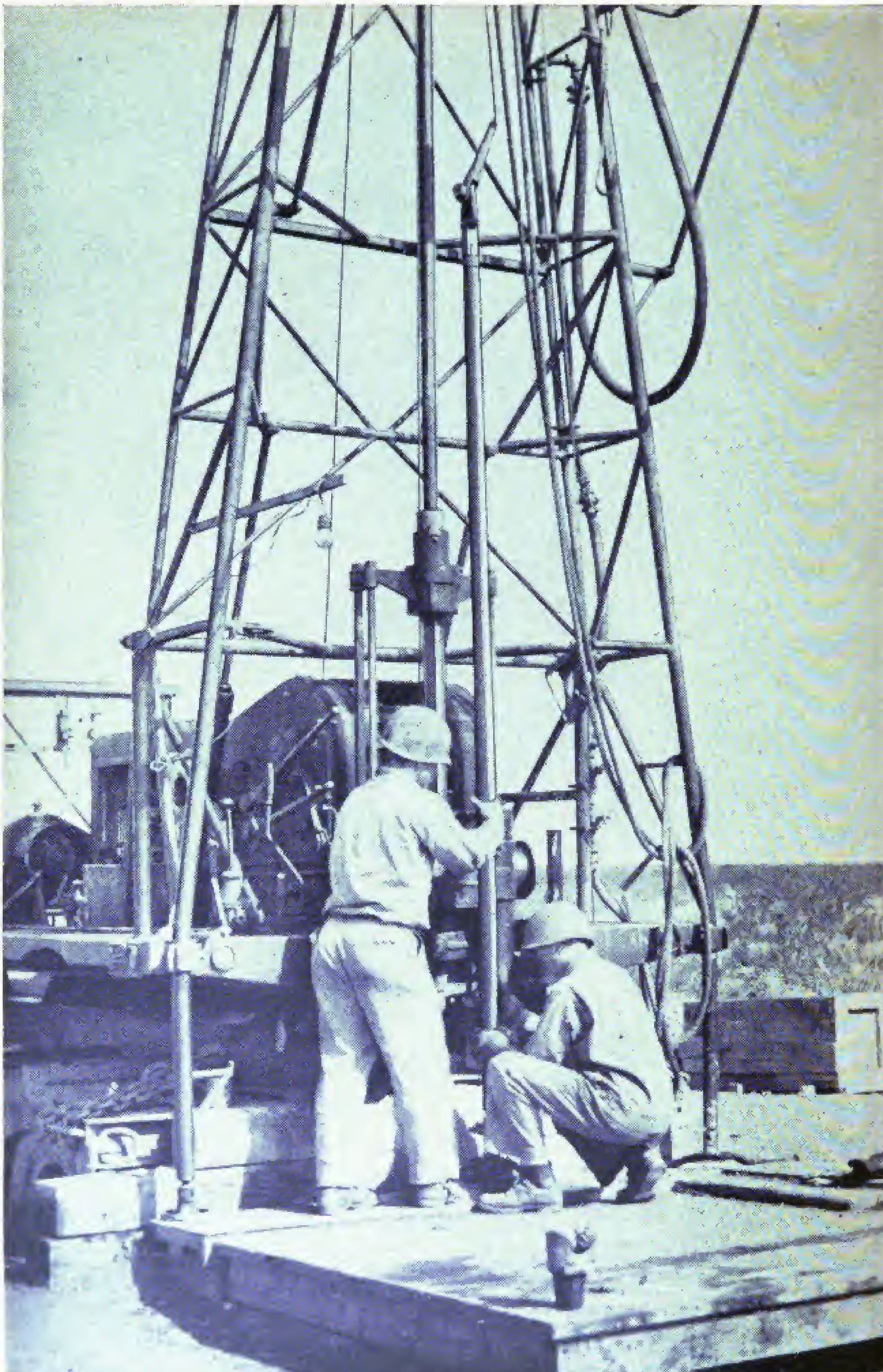


Figure 51. Rotary drill in operation, a new drill rod being added.

(4) If it is necessary to change bits before the hole is completed, the kelly is disconnected and the drill head moved back in the manner described for adding another joint of drill rod. The hoisting line is detached from the swivel and fastened to the hoisting plug. The rods then are pulled in doubles, or in 20-foot lengths. A board is placed on the ground so the bottom ends of the rods will not get dirty. If the hole is completed, the drill rods are pulled in singles and placed on a rack.

b. Drilling speeds. (1) The model 314 rotary well-drilling machine has been given intensive tests by the Desert Test Branch of the Engineer Board. The following drilling speeds could have been increased if the operators had been drilling test holes with no intention of setting well casing.

(a) Drilling unconsolidated formations. Holes varying in diameter from 4⅞ to 20 inches were drilled to depths of 940 feet in unconsolidated sand, gravel, and clays. When drilling a hole of 4⅞ -inch diameter, drilling speeds of approximately 60 feet per hour were attained. By the use of proper drilling mud and proper operational procedure, deep holes in unconsolidated caving formations can be held open without the use of casing while the hole is being drilled.

(b) Drilling hard rock. In hard granitic and basaltic rock, the machine operated satisfactorily. Drilling rates as high as 6.1 feet per hour were attained in granitic rock, and 6.9 feet per hour in basaltic rock. In drilling this type of rock, however, the expenditure of rock bits is high. The rotary rock bit is a highly specialized part of the equipment, and cannot be resharpened or built up in the field; it must be replaced when worn out.

(2) Higher drilling rates than those listed above often are attained, especially when drilling in limestones, dolomites, or poorly cemented sandstones. For the drilling performance of rotary drilling machines refer to table I.

61. CASING.

a. In areas where the surface formations are soft or sandy, it is necessary to set surface casing to keep the walls of the hole from caving, and to prevent the hole being enlarged by the washing action of the circulating fluid.

b. To set surface pipe, the hole is drilled or reamed so it will accommodate the casing. Surface pipe is set through surface formations and seated in a firm formation. To run the casing, a sub is attached to the hoisting plug and screwed into a joint of casing. It then is run into the hole in the same manner as the drill pipe. If the hole has caved so the casing will not go down, attach the swivel to the casing with a sub and

circulate fluid through the casing. This is called washing down, and sometimes is used in washing the drill pipe to the bottom of a caving hole.

c. The top of the surface casing should lie just below the spider base. A pipe clamp (fig.) 52 is clamped around the casing, to prevent it from dropping into the hole if the formation is washed from beneath it.

d. After completing a hole the walls must be supported to prevent caving and to protect them against contact with the water.

e. The casing is set in the hole as described in C above, except that in handling heavy or long strings of casing a traveling block (fig. 45) is used for safety. Wells drilled by the rotary method usually have the screen or strainer attached to the bottom of the casing, and set with it.

f. Setting well screens is discussed in greater detail in paragraph 67.

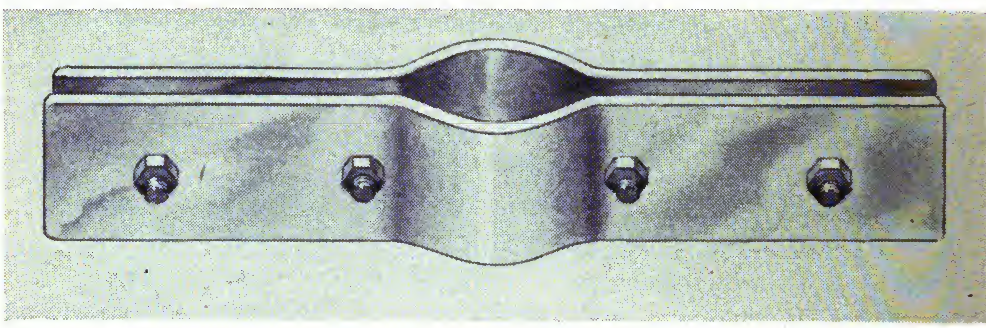


Figure 52. Pipe clamp.

62. SAMPLING AND CORING.

a. Formation recognition. (1) Successful well drilling, whether for water or for geological information, depends upon the ability of the driller to recognize formations, and changes in formations, as the drill penetrates them. He must keep a written log of the formations noting their colors. To be able to do this, the driller studies the characteristics of all the formations in the area of operation.

(2) An experienced rotary driller recognizes changes in formations by the action or sound of his equipment, the action of the drill pipe, and the behavior of the circulating pump. An examination of the drill cuttings deposited in the return ditch indicates more definitely the character of the formation.

(3) An accurate account of the depth of the bit below the surface is kept to log correctly the formation changes. To correlate the samples of cuttings from the ditch with the reaction of the drilling equipment to the formations from which they come, it is necessary to know the time required for the samples to travel from the bottom of the hole. This differs with the size and depth of the hole and the capacity of the mud pump.

b. Rotary samples. **(1)** When properly taken rotary samples usually identify water-bearing formations in shallow-water-well drilling. Samples are taken every 5 feet; more often if the occasion warrants. After taking each sample, the bit is hoisted about 1 foot off the bottom and rotated slowly while the mud circulation is kept up to full volume. This is continued until the mud is comparatively free of drill cuttings. After this operation is completed, drilling is resumed for another 5 feet, after which the drill pipe is raised slightly and the hole circulated until it again is clean of drill cuttings. If this cycle is followed, and the mud is screened carefully as it flows over the top of the well casing, samples usually can be caught with which to identify the different beds. This operation often can be simplified when the driller is familiar with the formations and conditions in the locality.

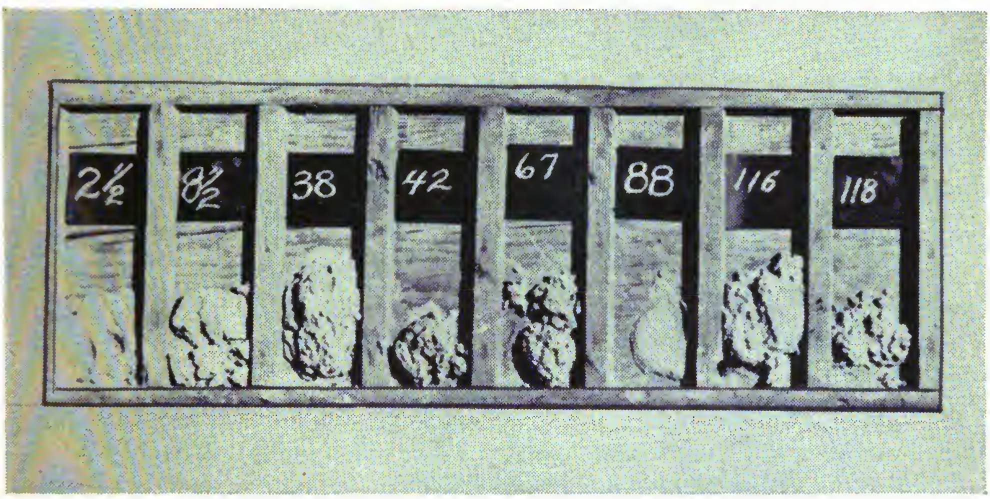


Figure 53. Samples from rotary hole.

(2) If an uncontaminated sample from the formation is desired, stop drilling and continue circulation until all cuttings are washed to the surface. Clean the ditch, proceed with drilling for a few inches, and again wait until cuttings are washed out. This sample represents the material being drilled. The bit penetrates deeper in soft formations than in harder formations while cuttings are being washed to the surface. Samples saved are placed in canvas bags or on sample boards (fig. 53).

c. Well log. The well log is a written record of the geologic formations met as the well is drilled. It records their depth, thickness, and chief characteristics, such as texture, color, hardness, and whether they appear to be water-bearing. An accurate record of the amount of drill pipe in the hole is kept. In recording the thickness of a formation, the depth to both top and bottom of the formation are shown. For example, if water-bearing sand and gravel are met at a depth of 125 feet, and the formation

is 42 feet thick, the log reads "125′ to 167′—sand and gravel (water bearing)." A written record of the formations drilled is invaluable when a second hole is drilled in the immediate vicinity, since the driller knows when he can expect to encounter a water-bearing formation.

d. Coring. (1) Core barrels. (a) In drilling holes for geologic information, or when it is necessary to obtain a more complete picture of the formation than is furnished by cuttings, cores are required. A core is obtained by attaching to the bottom of the drill pipe a simple device called a core barrel in place of the regular bit.

(b) Core barrels differ in design, but work on the same principle. Most of them consist of two concentric tubes with an annular space between for the passage of circulating fluid (fig. 54). The outer tube has several pieces, the upper part attaching to the drill pipe and the lower to the bit. The inner tube is held in place either by the cutter head or bit at the bottom, or by a swivel head at the top. The top of the inner tube is closed and has a vent valve which allows the pressure to be relieved from the inner tube but does not allow the circulating fluid to enter. The cutter heads or bits differ in design. Some are of the shearing or drag type; others are of the roller-cutter type; still others are set or studded with cutting media such as tungsten carbide inserts, or, in mineral exploration, bortz or black diamonds. All coring bits cut an annular ring or kerf. As the bit penetrates the formation, a core of material protrudes up into the inner tube where it is held by a lifter or gripping device.

(c) A core barrel of the above type usually is long enough to take 10 feet of core, after which it is pulled. Another type, used in drilling deep wells, is made so the inner tube can be withdrawn through the drill pipe. Thus it is necessary to pull the drill pipe only when replacing worn-out cutters or bits.

(2) Improvised core barrel. (a) Coring rarely is necessary in shallow water-well drilling, and none of the special coring equipment described above is provided with Corps of Engineers standard rotary tools. However, if cores are required, a satisfactory core barrel can be improvised from a piece of 3- or 4-inch pipe, threaded on one end and tapped with a 1/2-inch hole, 12 inches from the threaded end. This hole acts as an outlet for the circulating fluid. The opposite end of the pipe is serrated completely around its perimeter with pointed teeth about 3 inches deep. A reducing nipple, which is standard equipment, then is used to attach this core barrel to the bottom of the drill pipe.

(b) When such a core barrel is used, it is let down with the pump running at high speed, and stopped within a few inches of the bottom of the hole. The purpose is to flush out the core barrel and wash clean the bottom of the hole. Then the core barrel is lowered slowly into the for-

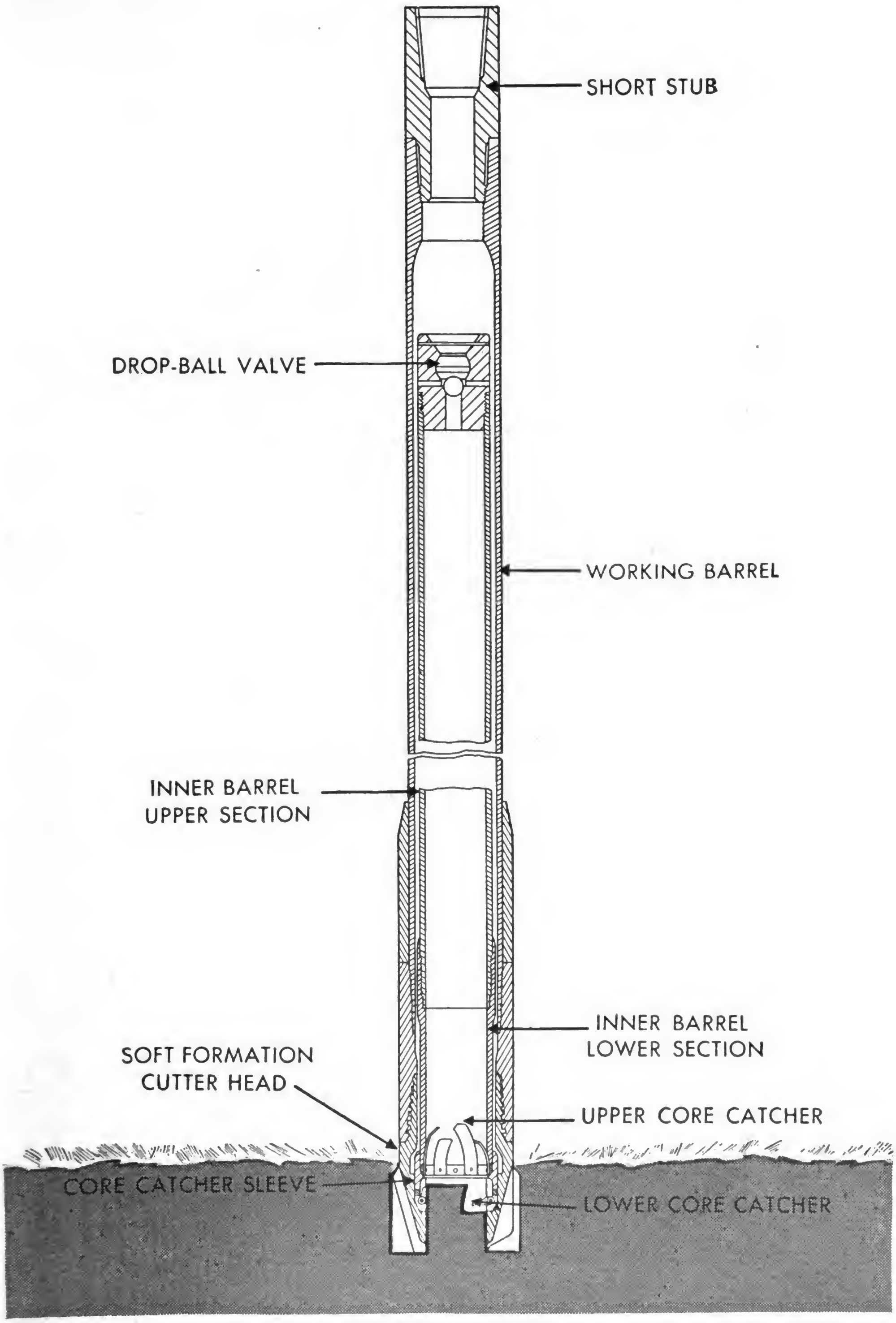


Figure 54. Core barrel.

mation, with minimum pump pressure and rotating speed. When the core barrel has penetrated the formation 12 to 18 inches, the pump is stopped, the rotating speed increased, and higher pressure is applied to the core barrel. This causes the teeth on the lower end to bend inward and retain the core. No more than 30 to 40 seconds are necessary for this last operation. The core barrel then is brought to the surface.

63. RECOGNITION OF WATER-BEARING FORMATIONS.

a. If the geology of the area is imperfectly known, the search for water-bearing beds must be done carefully and deliberately and all possible water-bearing horizons tested. Many wells capable of producing water are abandoned as dry because of incompetent drilling.

b. There are no infallible criteria for the recognition of water-bearing horizons. Some horizons may include fissured or cavernous limestone or basalt, crushed or fractured zones in consolidated sedimentary, igneous or metamorphic rocks, loose sands and gravels, sandstones and conglomerates, or hard fractured shales. In prospecting for water, all possible water-bearing beds are tested, even at shallow depths. Sticky clays, tough plastic shales, thoroughly cemented sandstones and conglomerates, and massive unfractured limestones or other dense rocks, seldom contain available water.

c. An experienced man generally can make a rough estimate of the permeability of the formation by examining the drill cuttings and, if necessary, a more accurate porosity determination can be made in the field camp. The following criteria, based upon changes in the character and circulation of the mud, indicate some of the most important means of recognizing water-producing zones.

(1) There usually is a slight loss of circulating mud while drilling, caused by natural seepage. This requires the continuous addition of a small quantity of water to maintain sufficient volume for circulation. Where the loss becomes excessive, 5 gallons per minute or more in a 500-foot, 5 5/8-inch hole, the depth at which the loss occurs is noted carefully and formation samples are taken frequently, so a suitable screen can be set at this level.

(2) A noticeable increase in the volume of the returning circulation fluid invariably means that a water-bearing formation has been met which has a higher hydrostatic pressure than the mud column in the hole. When this occurs, the circulating mud rapidly loses viscosity and weight, and in extreme cases is displaced in the hole by water from the formation.

(3) Complete loss of circulation usually means that a large volume of water with a comparatively low hydrostatic pressure has been met. This is especially true in limestones.

64. TESTING WATER ZONES.

a. If the hole is being drilled in a hard, noncaving formation, the mud is displaced by circulating clear water through the drill pipe from the bottom of the hole. Then the hole is bailed, thus lowering the fluid level and allowing the water in the suspected zone to break into the hole, washing out the sealing mud in the porous zone. If the hole has been drilled in a soft, caving formation, displacing the mud with water and bailing the hole invariably results in slumping or caving of the walls. Frequently such caving "freezes" the drill pipe. In such soft material a formation-testing procedure is adopted.

b. Side-wall packers are large-diameter rubber and steel cylinders fixed to the bottom of the test casing string. The ordinary packer is not recommended, since caving above them may cause the test casing to stick, and make it impossible to pull the pipe. Recently developed small-diameter low-pressure packers are capable of expanding much wider than the ordinary casing packer. They can be reduced again to small size for removal from the hole when the test is completed.

c. One generally successful procedure is to drill a rathole, or small-diameter hole, until a suspected zone is penetrated. When such a zone is met, the hole is reamed out to full size down to a few feet above the top of the suspected zone. A test string of casing, which will pass freely through the large-diameter hole but will not enter the rathole, is then run. The casing is wedged or driven firmly into the rathole, thus sealing off the hole above the suspected zone. The space between the casing and the walls of the hole is kept full of mud fluid to maintain the hydrostatic pressure on the walls of the hole above the casing shoe.

d. The drill pipe or a wash pipe is run through the casing to the bottom. The mud in the suspected zone is washed out with clear water and the fluid inside the casing is bailed to test the volume and quality of the water in the suspected zone. While bailing, the level of the mud fluid outside the casing is carefully watched. If the level remains stationary, it is certain that the shut-off is satisfactory and that all fluid bailed out is coming from the formation under test. If the level drops while bailing, probably the shut-off is unsatisfactory, and fluid is leaking into the zone being tested. In that case the casing should be reseated or driven more firmly into the rathole and retested.

e. Flotation type formation testers are not recommended. This type tester consists of a valve or cast-iron plate sealing on the bottom of the test casing. The test casing is run into the rotary hole and wedged or driven into the rathole as in the previous case, but the bottom of the casing is sealed with a thin cast-iron plate, and the inside of the casing is dry. After sealing the casing shoe firmly into the rathole, a cast-iron

weight or "go-devil" is dropped into the casing. The weight breaks the thin cast-iron plug and lets the fluid in the suspected zone rush into the empty casing. If the zone has a plentiful supply of water, the water breaks down the mud seal or clogged zone and rushes violently into the casing, sometimes undermining the casing seat and permitting the fluid outside the casing above the slot to break in.

f. If the suspected zone is so tight that no water rushes into the casing, the fluid above the casing seat causes a large excess pressure on it. Unless the seat is particularly strong, the fluid above it may force itself with a rush around the shoe of the casing. If this occurs, the side walls above the seat are certain to slump and freeze the casing.

g. In bailing, any sudden lowering of the fluid level outside the casing indicates a leak past the seat. The test then is discontinued before the side walls cave in to freeze the pipe. After testing, the clear water in the hole is displaced with mud and the casing is pulled.

h. If no water has been found at the maximum drilling depth, but several suspected zones have been penetrated, gun perforating can be employed. A string of casing is run to the bottom, or at least to the bottom of all suspected zones, and the casing is cemented. Enough cement is placed so the space outside the casing is filled to a point well above the uppermost suspected zone. The lowermost suspected zone then is gun-perforated, and the bailing test is applied. If that zone is dry or has an insufficient supply of water, each succeeding zone up the hole is similarly tested. If the tests are dry, and it is desired to abandon the hole, only that part of the casing above the cement line can be recovered.

65. DRILLING DIFFICULTIES.

a. Lost circulation. Zones of lost circulation, sometimes encountered in shallow water-well drilling, are zones of high porosity usually containing large supplies of water. Hence, a test of the well always is made when circulation is lost. Formations which drain off or absorb all or part of the circulating fluid offer problems ranging from minor inconveniences and loss of time to extreme conditions which render rotary drilling impracticable. These formations can be divided roughly into three classes:

(1) Formations which contain joints and fissures, such as quartzite, sandstone, limestone, and dolomite. The chief difficulties encountered in drilling these formations arise from caving, abrasion, and total loss of circulation.

(2) Shale which is jointed and fissured seldom drains off an excessive amount of the circulating mud. However, the mud absorbed causes

the shale to swell and heave, filling up the drill hole. Modern drilling practice largely has overcome this difficulty by the use of special circulating equipment and drilling mud not available to the Army driller. However, the conditions outlined above seldom are encountered, and satisfactory drilling progress usually is made by using a mud of high viscosity and weight.

(3) Sands and gravels seldom absorb enough of the drilling mud to hinder drilling progress seriously. The loss, which is continuous, is replaced not with water but with mud. Water, when used to maintain sufficient volume for circulation, soon lowers the viscosity and weight of the mud and caving results.

b. Regaining lost circulation. Where it is desirable to regain lost circulation, one of the two methods described below is used:

(1) The method usually found most satisfactory in water-well drilling is to drill through the zone of lost circulation and to set a string of well casing somewhat below the porous zone. The chief requirement is a plentiful supply of water to circulate the cuttings away from the bit and into the formation. Mud is desirable for this purpose but the quantity needed usually precludes its use. When using water to carry off the drill cuttings always remember to continue operating the pump for a few minutes after drilling has stopped. This flushes the cuttings out of the hole and prevents the drill pipe sticking when it is stopped to make a connection. In extreme cases where it is necessary to drill as much as 100 feet or more, a small quantity of rotary mud is "spotted" around and above the bit while an additional joint of pipe is installed in the drilling string. This prevents excessive settling-out of the drill cuttings and consequent sinking while the drill pipe is standing. When the bottom of the porous zone has been reached, drilling is continued into the underlying formation for about 50 feet, to give room for cementing the casing. When the casing has been run and cemented, ordinary rotary-drilling procedure is resumed.

(2) Usually the circulation can be regained by mixing a fibrous material with the drilling fluid. This material may be bought commercially. In an emergency, cotton seed hulls, bran, sawdust, shredded hay, or like substances may be substituted. In some cases the hole must be abandoned. If circulation is lost in cavernous lime, the fluid level in the hole is checked and tested for fresh water.

c. Holes. (1) Straight holes. (a) A straight hole often is the determining factor between a cheap, abundant supply of water and a loss of all the work and equipment involved. Much depends on the experience and ability of the drill operator when drilling through difficult formations. Some of the important points for straight hole drilling are:

1. The diameter of the hole never exceeds twice the diameter of the drill pipe.

2. From 25 to 100 feet of drill collars are used in the drilling string.
3. Speed of bit rotation is at least 150 rpm.
4. Mud circulations are 50 gallons per minute per inch of the bit diameter.

(b) The above mechanical considerations are not feasible for the small rotary-drilling machine, though they can be compensated to some extent by an experienced operator. The harder formations, especially those which are dipping and those which are broken and creviced, present many difficulties. The only bits employed in the difficult formations are the roller-rock bits and the three- or four-wing drag bits. Fishtail, diamond point, and some of the single-cone roller bits are not suitable for anything except the softest formations; even then their use is questionable.

(2) Crooked holes. (a) Crooked holes that would seriously damage pumping equipment can be drilled without noticeable effect on the drilling machinery or equipment. Straightness must be determined in other ways. The simplest method is the acid bottle or tube partly filled with hydrofluoric acid and placed inside the drill pipe. Then the pipe is run in the hole and stopped opposite the point to be surveyed. When the pipe is held perfectly still for a few minutes, the acid etches a horizontal line around the inside of the tube at the surface of the acid. By calibrating this line, the degree in which the hole varies from the vertical is ascertained with some accuracy.

(b) Another way to detect crooked holes is to watch for wear on the drill pipe. If it occurs at a set distance from the top of the ground it indicates the hole was deflected at this point.

(c) To avoid crooked holes, the bits should be of a form and size that prevent undue eccentricity during rotation. They must be sharp, and dressed to proper gauge. The drill collar which holds the bit to the lower end of the drill pipe must be large enough in diameter to hold the pipe centrally in the hole and to prevent the bit from working off to one side. Excessive bit pressures are avoided.

(d) The usual method to straighten crooked holes is to set the bit where the hole starts off the vertical and rotate it until a shoulder is started, gradually working down to the bottom of the hole. This is a slow, difficult operation and is not successful in the harder, more difficult formations. The best method is to ream the hole to the largest possible diameter, to give the well casing or pump pipe a chance to align itself in the hole. This method often succeeds when other methods have failed.

d. Cause, prevention, and recovery of stuck drill pipe. A rotary drill pipe usually sticks or "freezes" in shallow (1,000 feet or less) rotary holes for one of the following reasons:

(1) Inexperience of operator. This means the operator lacks

knowledge of rotary-drilling procedure over and above the mere operation of the drilling machine. He must have a working knowledge of the use and conditioning of mud, and be able to detect signs of trouble in time to take preventive measures. Two examples which illustrate this more fully are given below:

(a) The drill pipe is kept free in the hole by simultaneously rotating the pipe and circulating a mud-laden fluid. If either operation stops, only a limited time should elapse, depending upon the formation penetrated, before pulling the bit up into the casing, or out of the hole altogether if no casing has been installed. Failure to do this often results in the drill pipe's sticking because of the sand and drill cuttings which settle around it.

(b) Formations often are encountered which drain off or absorb a certain percentage of the drilling mud being circulated in the hole. When this happens, it is necessary to keep adding to the fluid in the hole to maintain circulation. If clear water is used, trouble soon develops, as the water, when used in considerable quantity, thins the mud to a point where it exerts a cutting action on the walls of the hole and causes extensive caving around the drill pipe, fastening it securely in the hole.

(2) Inadequate equipment. A good example of this is a mud pump which does not have sufficient capacity to keep the drill cuttings and cavings flushed out of the hole. This fault is especially noticeable in holes where the formation caves, often causing large-diameter holes. When the returning circulation enters one of these recesses, it is slowed down so the drill cuttings settle out and form deposits which fall back around the drill pipe when the pump is stopped, often sticking it.

(3) Balling up. This is the accumulation of soft, sticky shale or clay around the bit and drill collar. Occasionally, mud collars are formed which are forced up the hole by the pump action. This balling up, if allowed to continue, forms a coating around the drill collar which sticks the drill pipe securely when it is raised off bottom. The usual cause for balling up is a high rate of penetration combined with a speed of rotation insufficient to mix the drill cuttings thoroughly. When these conditions are encountered, the drill pipe is "spudded" frequently by raising it off the bottom and dropping it 4 or 5 feet at a time while the pipe is being rotated rapidly. If this is done and if the rate of penetration is held to a speed which gives the circulating fluid time to mix the drill cuttings thoroughly, this source of trouble can be held to a minimum.

(4) Lost circulation. This often causes drill pipe to stick when a crevice or formation which drains away the drilling mud is penetrated. Limestones are troublesome in this respect, especially porous limestones, which contain much water. When one of these zones is penetrated by the drill, the hydrostatic pressure of the drilling mud causes it to drain

rapidly into the formation. The sudden reversal of the circulation in the hole deposits the suspended drill cuttings around the drill pipe, usually sticking it tightly. This often happens so suddenly that there is little or no time to remove the drill pipe.

(5) Recovery. (a) Recovery of stuck drill pipe in wells drilled with the rotary equipment found in the Corps of Engineers is limited, as in all shallow-water well drilling, by the capacity of the drill and the amount of auxiliary equipment available. Every precaution is observed to prevent the drill pipe from sticking, as only an extreme scarcity of drill pipe justifies extensive fishing jobs in shallow-water well drilling. However, there are a few things which sometimes can be done successfully with the equipment at hand, depending upon how tightly and in what manner the drill pipe is stuck.

(b) If the drill pipe is stuck by "balling up" while drilling in soft shale or clay, often it can be loosened by circulating clear water. An upward strain should be kept on the pipe while the water is being circulated.

(c) When the pipe is stuck by sand or drill cuttings accumulating in the hole, circulation should be maintained with the heaviest mud obtainable; if possible, the pipe should be worked. Any movement transmitted through the pipe, however slight, helps dislodge the sand particles into the mud stream, where they are carried to the surface.

(d) When heaving shale sticks the pipe, probably the best method of loosening it is to spot oil along the portion of the pipe that is stuck, moving the oil every 2 hours with a few strokes of the pump, meanwhile keeping a strain on the drill pipe with the machine. Oil should be used cautiously in drilling water wells, for often it contaminates adjoining wells in addition to the one in which it is used.

(e) When a drill pipe is stuck through loss of circulation, little can be done toward recovery of the entire string of pipe. However an attempt should be made to pull the pipe with the jacks. This is only sometimes successful for the small rotary has a limited hoisting capacity.

(f) Sometimes the pipe can be recovered by mixing the proper circulating fluid and circulating it while working the pipe with both rotation and hoisting mechanism. Sometimes it is necessary to circulate oil instead of mud to loosen stuck pipes. If circulation has been lost and cannot be regained, probably it will be necessary to wash over the drill pipe with casing in order to recover it.

e. Fishing. (1) The most frequent type of fishing in rotary drilling results from twisting off the drill pipe. Such "twist-offs" usually occur near the lower end of the pipe; they may consist of a simple shearing off of the pipe or of a fracture at a coupling. The accidental dropping

of a drill pipe into a hole also calls for fishing. Among the less common accidents requiring fishing are the dropping of tools, such as slips or wrenches, into the hole. Certain general principles apply to all fishing jobs. One thing to remember when failure occurs is its exact depth. Fishing tools are discussed in paragraph 51.

(2) In drilling shallow wells, often it is cheaper to abandon the hole and the lost tools than to spend time fishing for them. In some cases lost tools may be sidetracked by drilling past them.

66. WELL SCREENS AND ACCESSORIES. Two types of screens are furnished for use with rotary drilling equipment:

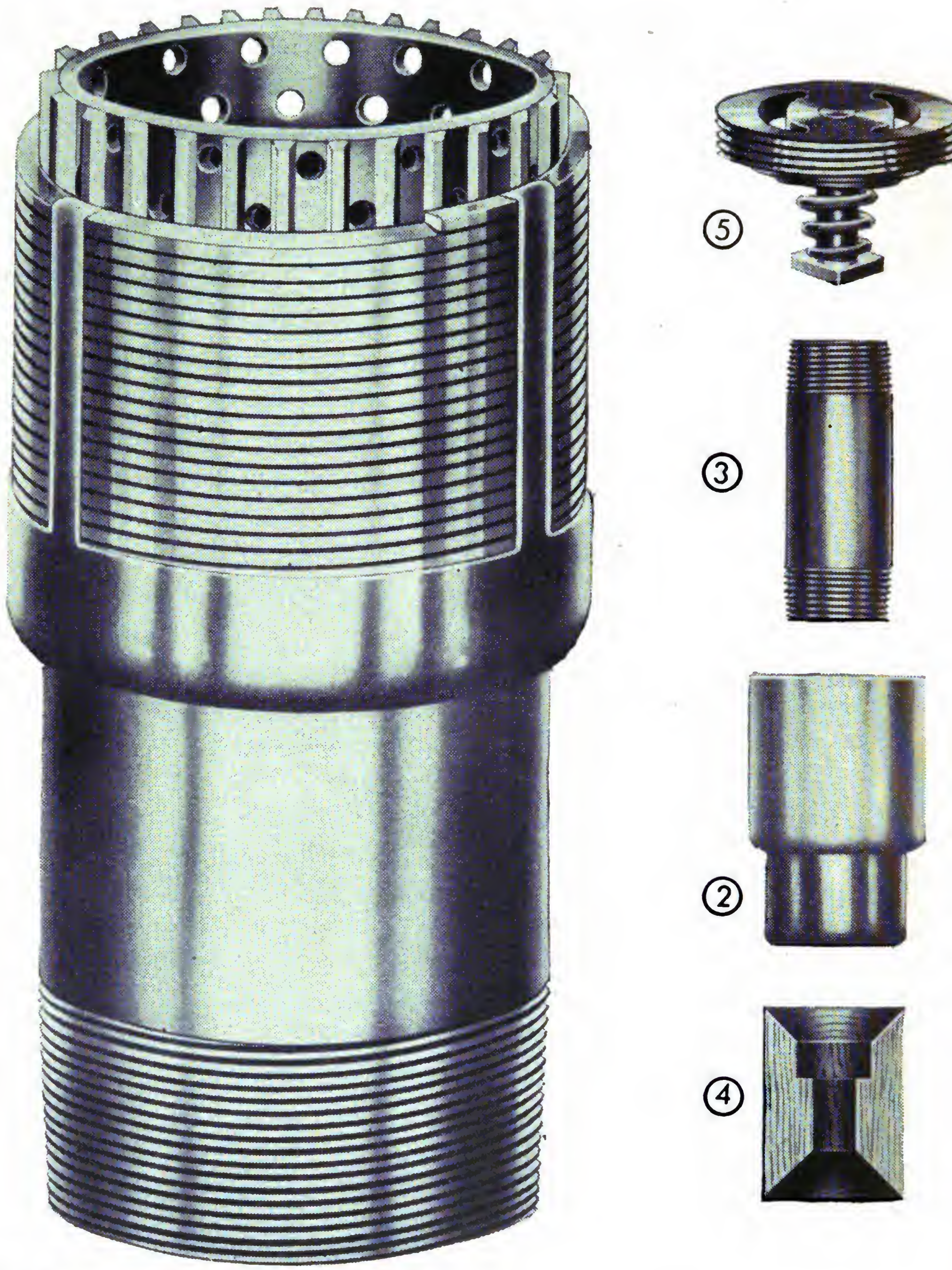
a. Wire-wrapped pipe screens. Wire-wrapped pipe screens (fig. 55 (1)) are made on a perforated pipe base with vertical rods extending along the length of the perforated pipe, and a triangular or keystone-shaped wire wrapped around the rods. The wrapping wire has slots accurately placed. These screens are furnished in two sizes, one with 3-inch line pipe threads and the other with 4-inch line pipe threads. They have slot openings sizes 30 and 40, and each is equipped with a pressure valve, wood wash plugs, and "mule-foot" nipples. (See fig. 21 for description of slot sizes.) Fittings are furnished in 3- and 6-inch sizes.

(1) Back-pressure valve. The back-pressure valve used with this screen is a common type (fig. 55 (5)). The threads on the outer perimeter of the seat plate are identical with those of the pipe, and therefore will fit inside a coupling. Usually the valve is placed inside the bottom coupling below the screen and immediately above the guide plug or "mule-foot" nipple and below the wood wash plug (fig. 55 (4)).

(2) "Mule-foot" nipples. The "mule-foot" is a short nipple of the same diameter as the pipe, with one end cut at a 45° angle. The other end of the nipple has a standard pipe thread which will enter the size coupling used. The nipple is placed just below the back-pressure valve.

(3) Wood wash plug. The wash plug (fig. 55 (4)) is a wooden plug of the same diameter as the inside diameter of the well casing. It is bored so that the drill rod of a rotary well rig will seat in it to form a reasonably tight joint. It prevents water coming back up through the casing when the water is forced down through the base of the drill rod into the formation outside the casing, to wash the drill mud from around the screen.

b. Wire-wrapped vertical rod screens (fig. 56). The screens or strainers now being supplied are the wire-wrapped vertical-rod type of welded or caulked construction. These screens do not have a pipe base. The screens are furnished in 10-foot lengths of 5⅝-outside diameter and 3¾-inch outside diameter; the first for 6-inch, the latter for 4-inch casing. The screens have male pipe threads on each end provided with fittings



① *Wire-wrapped, perforated well screen.*
② *Lead seal on pipe coupling.*
③ *Pipe nipple for attaching to lead seal.*
④ *Wood wash plug.*
⑤ *Back-pressure valve.*

Figure 55. Wire-wrapped screens and accessories.

having female threads. Some of the screens have a fairly fine 16-slot opening, and the others a relatively coarse 40-slot opening. These screens can be set in either rotary- or percussion-drilled wells. The following screen fittings illustrated in figure 56 are furnished:

(1) Valve, back-pressure, with male threads to screw into lower end of casing. The mule-foot nipple is not needed with this valve.

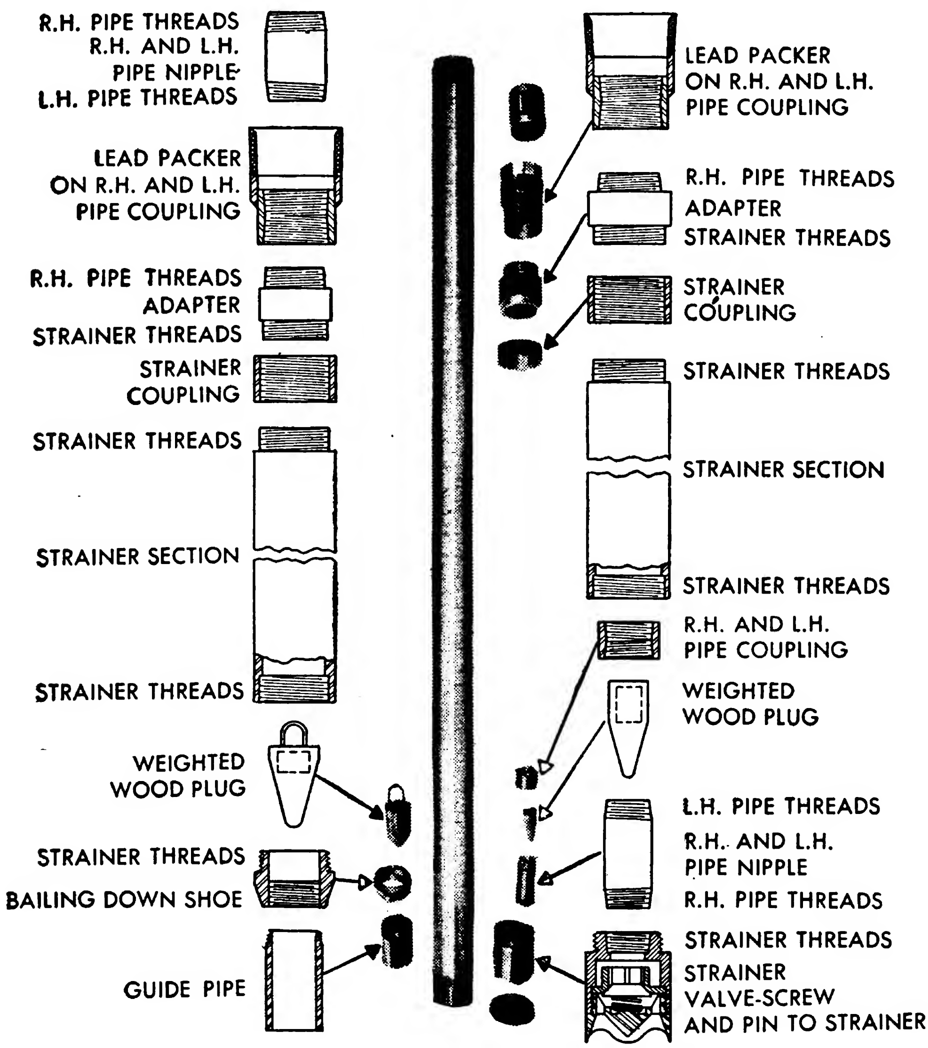


Figure 56. Continuous-slot, wire-wrapped, vertical-rod well screen.

(2) Plug, wood wash, to fit into back-pressure valve.

(3) Nipple, 2-inch pipe with right-hand threads on one end and left-hand threads on the other.

(4) Coupling, 2-inch pipe, with right-hand threads on one end and left-hand threads on the other.

(5) Adapters, for connecting the screens to 4-inch standard pipe and 6-inch drive pipe.

(6) Packers, lead, fitted with male screen coupling threads to screw into the screens for sealing the screens in 4- and 6-inch pipe.

(7) Nipple, 4-inch, with right-hand threads on one end and left-hand threads on the other.

(8) Plugs, bail, with male threads for screwing into bottom of screens.

67. SETTING SCREENS. The two principal methods of setting well screens in rotary-drilled wells are the single-string method (fig. 57) and the double-string method (fig. 58).

a. Single-string well-screen setting. (1) The single-string method (fig. 57) is used most commonly in setting screens with the rotary machine.

(2) In preparing the screen for running into the hole, it is fitted with a foot-valve assembly consisting of a pipe coupling, foot valve, wash plug (either wood or metal) and a mule-foot nipple or guide plug. The screen is connected to the bottom of the first length of casing and run into the hole as the casing is lowered.

(3) With the screens located in the water-bearing formation, the hole and producing formation are flushed free of drilling mud. This is done most satisfactorily by running the drill rods into the pipe until the lower end rests on top of the wooden wash plug in the lower end of the screen. The water swivel then is connected to the top of the drill rods, and clear water is circulated to remove the drilling mud from around the screen. After the hole has been flushed clean, the drill rods are pulled from the hole.

(4) The screen then can be flushed thoroughly from the inside by screwing to the bottom of the drill rods a special coupling with its lower end sealed and holes drilled around its perimeter. When the pump is started, the water is forced out the sides of the coupling into the screen openings. Raising and lowering the drill rods the full length of the screen results in a thorough cleaning of its openings.

(5) As illustrated in figure 57, only a short wash pipe is used in the screen and lower part of the casing. A wood wash ring has been placed in the top coupling of the screen to centralize the wash pipe and to direct the water down through the wood wash plug and back-pressure valve during the setting of the well pipe and casing. After the screen is set, the wash pipe has to be fished out by a taper tap, spear, or overshot; the wood wash ring is broken in withdrawing the pipe. This method is not as simple as the one previously described wherein the screen is run with the casing and the drill rods are lowered into the well to flush it. This method is good, however, for washing the screen and pipe in place when the hole has partially caved.

b. Double-string well-screen setting. (1) In the double-string method of setting well screens (fig. 58) the well casing first is placed in the hole; then the screen and wash pipe are connected to the string of pipe as

described in the single-string method, and the screen is lowered into place. The top of the screen is fitted with a lead seal which must be expanded with the swage block (fig.78) to make a sandtight seal between the screen

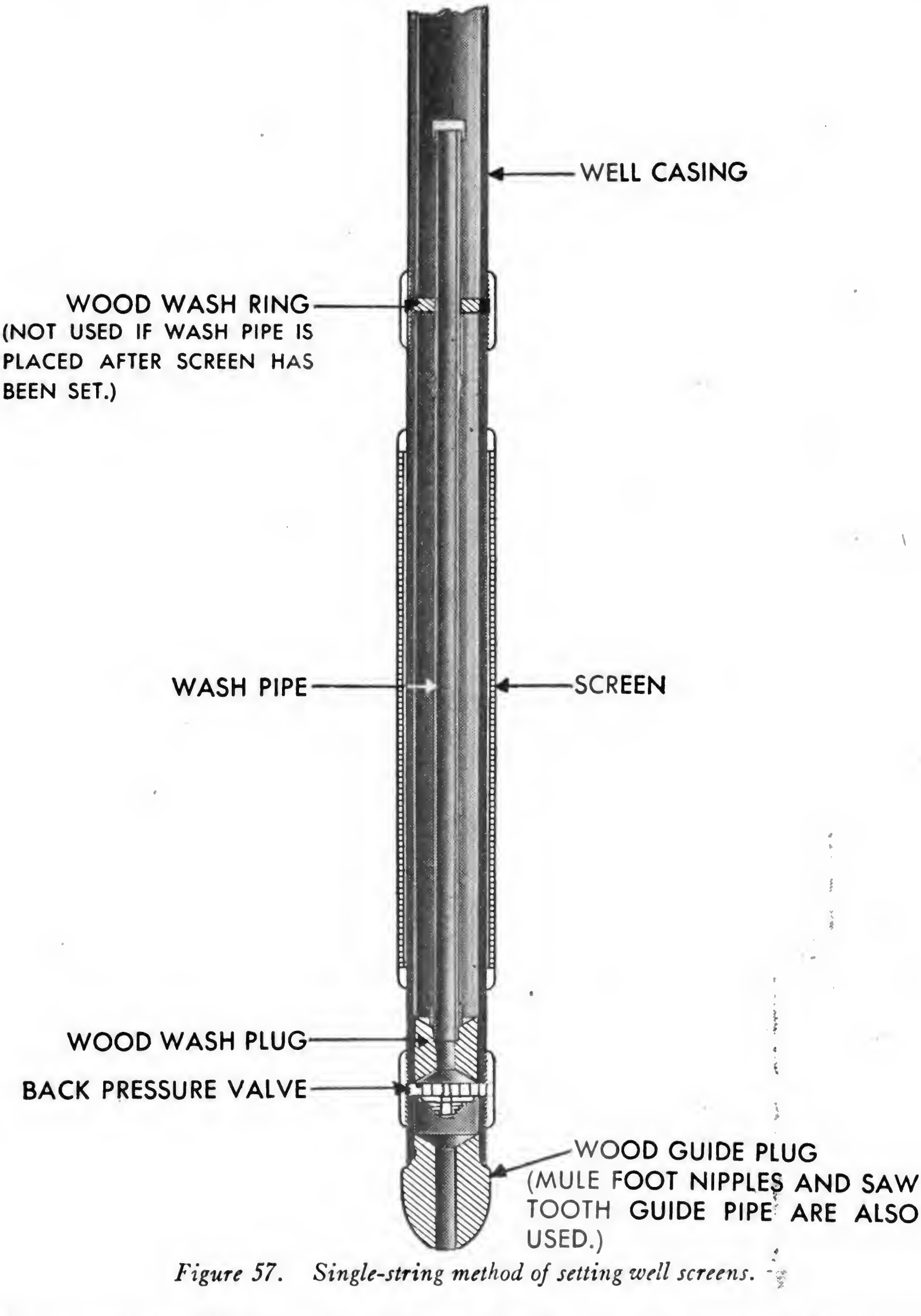


Figure 57. Single-string method of setting well screens.

and the casing. This method is used for jetting the screen into place in larger diameter and deeper wells.

(2) All screens furnished are equipped with accessories for both the single- and double-string methods. This method also is quite commonly

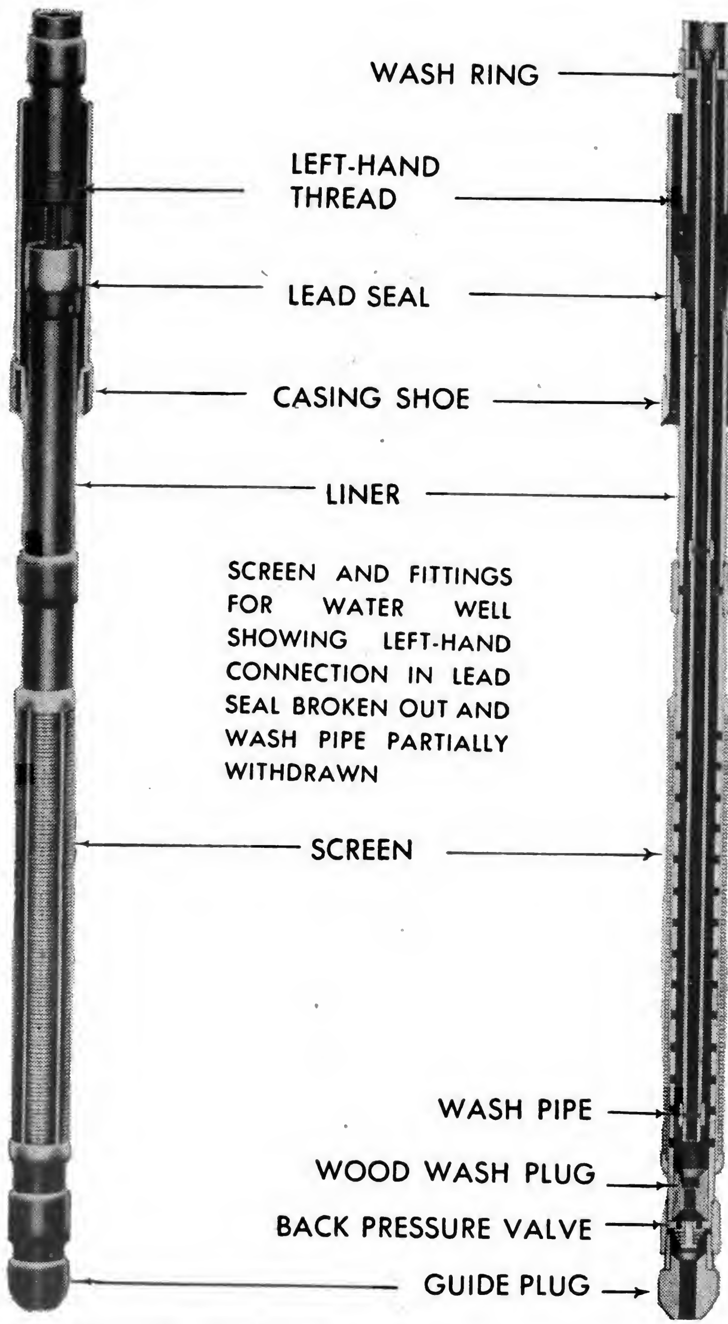


Figure 58. Double-string method of setting well screens.

used with percussion drilling machines where it is impossible to keep an open hole below the drive pipe. The screen is flushed and cleaned in the same manner as described, in **a** above.

c. Pull-back and bucketing-down methods. These methods of setting well screens are described under the percussion-drilling method in chapter 8. Neither is used frequently with rotary rigs, for they are much slower and with them it is less easy to set the screens in their proper place.

68. WELL DEVELOPMENT.

a. Bailing. The bailer ((4), fig. 31) is connected to the sand line with a swivel socket, and lowered into the hole by releasing the sand-reel drum brake. When the bailer is filled with water, it is removed from the hole, emptied, and lowered into the well again. Bailing is continued until the water from the well is clear.

b. Swabbing. In developing a well by swabbing, the swab illustrated in figure 44 is attached to the sand line by the sinker bar and swivel socket and lowered into the well. On its first trip the swab must not be lowered too far into the water, or sand may lock the swab in the pipe. The depth to which the swab can be submerged must be determined by the operator. An up-and-down motion given to the swab with the sand line stirs the water, loosening and removing mud and fine-grained material. After swabbing for a short time usually it is necessary to lower the bailer into the well to remove the material which has been pulled into the screen. Swabbing and bailing are continued until clear water enters the screen freely.

c. For further material on the development of wells, refer to chapter 9.

CHAPTER 8

PERCUSSION DRILLING METHOD

SECTION I

GENERAL DESCRIPTION

69. BASIC COMPONENTS OF PERCUSSION DRILLING MACHINE. The percussion drilling machine consists essentially of a mast; a two-line hoist, one line for operating the drilling tools and the other for operating the bailer or sand pump; a spudder for raising and dropping the tools; and an engine for power. The mast can be folded down over the machine for moving.

70. DRILLING PROCESS. Drilling breaks up the rock or loosens the material in the hole by means of the impact of a heavy bit and drill stem lifted and dropped at regular intervals, The loosened material, known as drill cuttings, is removed from the hole by a bailer or sand bucket. In drilling a dry hole, water must be added to replace that taken out in removing the drill cuttings. In hard rock, the hole usually is drilled without a casing, but in soft, cavey, or unconsolidated materials, casing is used to keep the hole open. It is driven down by fastening drive clamps to the drill stem, and hammering the casing.

SECTION II

DESCRIPTION OF STANDARD PERCUSSION DRILL STOCKED IN ARMY DEPOTS

71. GENERAL.

a. The No. 71 Speed Star percussion well-drilling machine is a portable rig that uses the spudding principle exclusively. The unit consists of a gasoline engine, drill frame, wire line spudder, air blower for the forge, drilling line, sand line, and an electric-welded structural mast. All controls are located at the right rear side, within easy reach of the operator. The unit is skid-mounted and can be operated on cribbing (fig. 59), or it can be mounted on a truck (fig. 60) or trailer (fig. 61).

b. The rated drilling capacity of the machine, using 3/4-inch drilling line, is shown in the table below. The weights shown are the maximum weights of the drilling tools, in pounds, that the machine is recommended to handle, in addition to the drilling line. The machine is designed to drill a hole 6 inches in diameter to a depth of approximately 1,000 feet.

Position of divider on bull reel	Depth of well (feet)				
	500	700	800	900	1,000
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1st position	2,000	1,800	1,700		
2d position		2,000	1,900	1,800	
3d position		2,100	2,000	1,900	1,800

NOTE. First position of single divider on bull reel is at set of holes nearest flange on blower side of machine.

c. The above recommendations are based on operation of the engine on standard-grade gasoline, and use of the longest stroke of the spudder, except that when the tool weight exceeds 2,000 pounds the next to the longest stroke should be used. Heavier weights can be handled by using a shorter stroke.

d. A detailed description of the major units, and the procedure in preparing the machine for service, are contained in TM 5–2002.

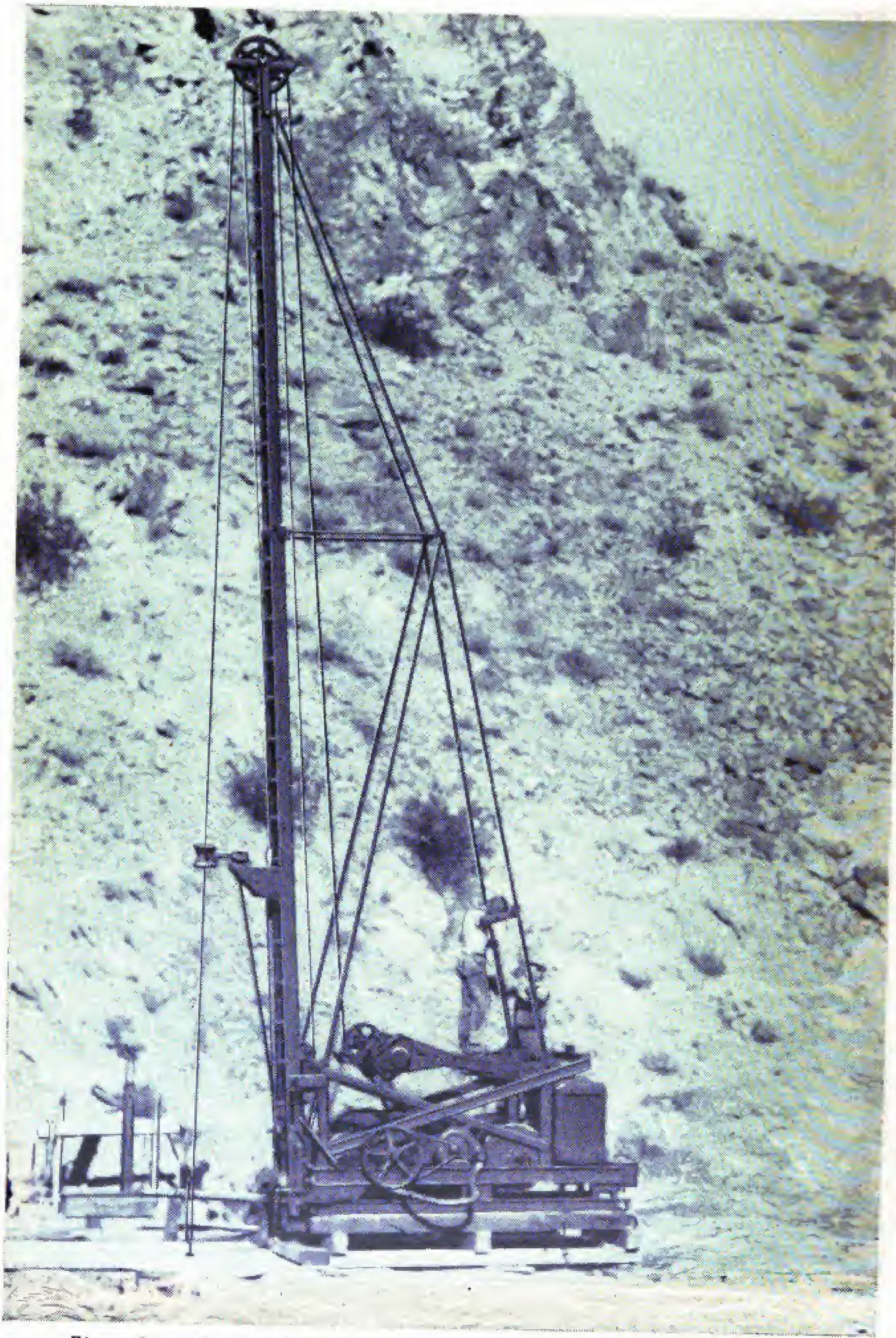


Figure 59. The No. 71 SK Star percussion drill set on cribbing for operation.

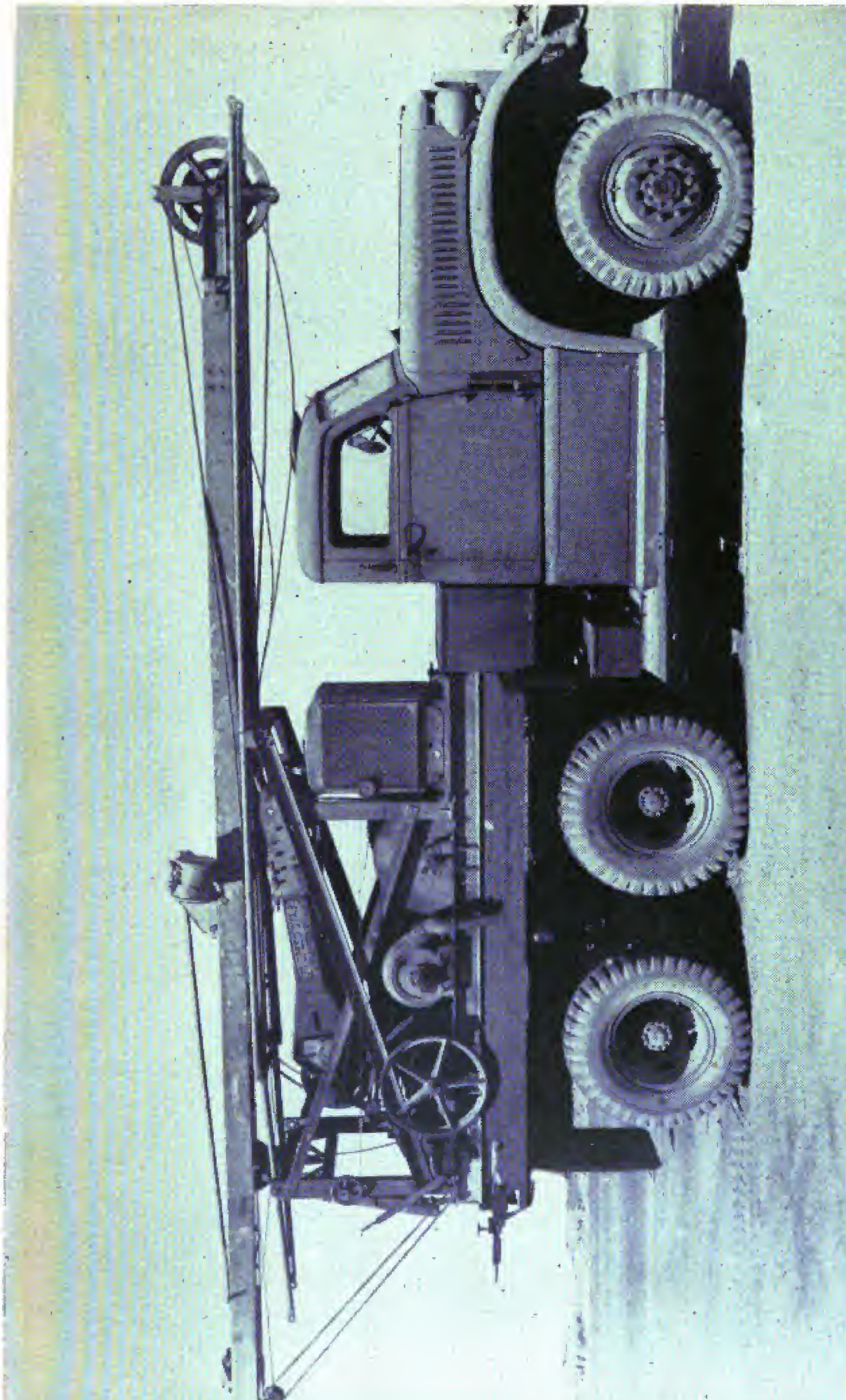


Figure 60. The No. 71 Star percussion drill mounted on a 152-inch wheel base, 6 x 6, 4-ton truck.

Figure 61. Unloading the No. 71 SK Star percussion drill from a low-bed trailer to cribbing.

72. FRAME.

a. The main frame is made of electrically welded steel. The main sills and all cross members are 6-inch beams. The cross members are dovetailed inside the main sills and are welded at the top and bottom flanges as well as at the web.

b. All shaft bearings are mounted directly on the main frame. All main bearings have four bolts that pass through both flanges of the I-beams. Each bearing is kept in alignment by either a machined seat or steel blocks welded to the frame.

c. The skids are standard size I-beams having ⅝-inch holes drilled in the bottom flanges for bolting the skid frame to cribbing. The skids are spaced so they can be secured with U-bolts to the frame of a standard U. S. Army 4-ton, 6x6 truck.

73. POWER UNIT. The power unit is a Model PF–162 Continental four-cylinder, water-cooled, gasoline engine with magneto ignition, equipped with oil filter, gasoline filter, oil-bath air cleaner, and radiator grill. Power is transmitted from the engine to the countershaft by V-belts.

74. SPUDDER. The spudding gear is in the center of the frame and is supported between two bearings mounted on center I-beams. The assembly consists of two forged crank arms driving two forged pitmans, which in turn operate two shock-absorbing spudder arms. The shock-absorbing mechanism, consisting of adjustable coil springs, is built into both arms of the spudder for the purpose of obtaining the proper spring tension in relation to the weight of tools used and the depth of hole drilled. Operating speeds and length of stroke are discussed under operation.

75. BULL REEL. The bull reel hoists and lowers the drilling tools in the well. It is driven by a roller chain with a 1½-inch pitch, and is engaged by a twin-disk clutch mounted on the countershaft. The bull reel drum has five positions in which to set the divider. Using the divider, the working and storage spaces for ¾-inch line are listed below.

Divider position	Drum capacity for ¾-inch line (feet)	
	Working space	Storage space
1st position	530	1, 200
2d position	740	990
3d position	950	780
4th position	1, 160	570
5th position	1, 370	360

76. SAND REEL. The sand reel is used for hoisting and lowering the bailer which removes drill cuttings from the well. The sand reel is driven by friction between a metal wheel on the sand-reel shaft and a fiber wheel on the countershaft. The sand-reel drum has a total spool capacity, without the divider, of 2,800 feet of ⅝-inch line. The machines are equipped with 1,200 feet of line.

77. MAST. The telescoping type structural-steel mast is 40 feet high when extended (fig. 59) and 22 feet high when telescoped. The manufacturer rates the mast at 15,000 pounds safe working load. The mast folds over the machine for loading and transporting. The crown and sand line sheaves are mounted on Timken bearings.

SECTION III

ACCESSORY EQUIPMENT

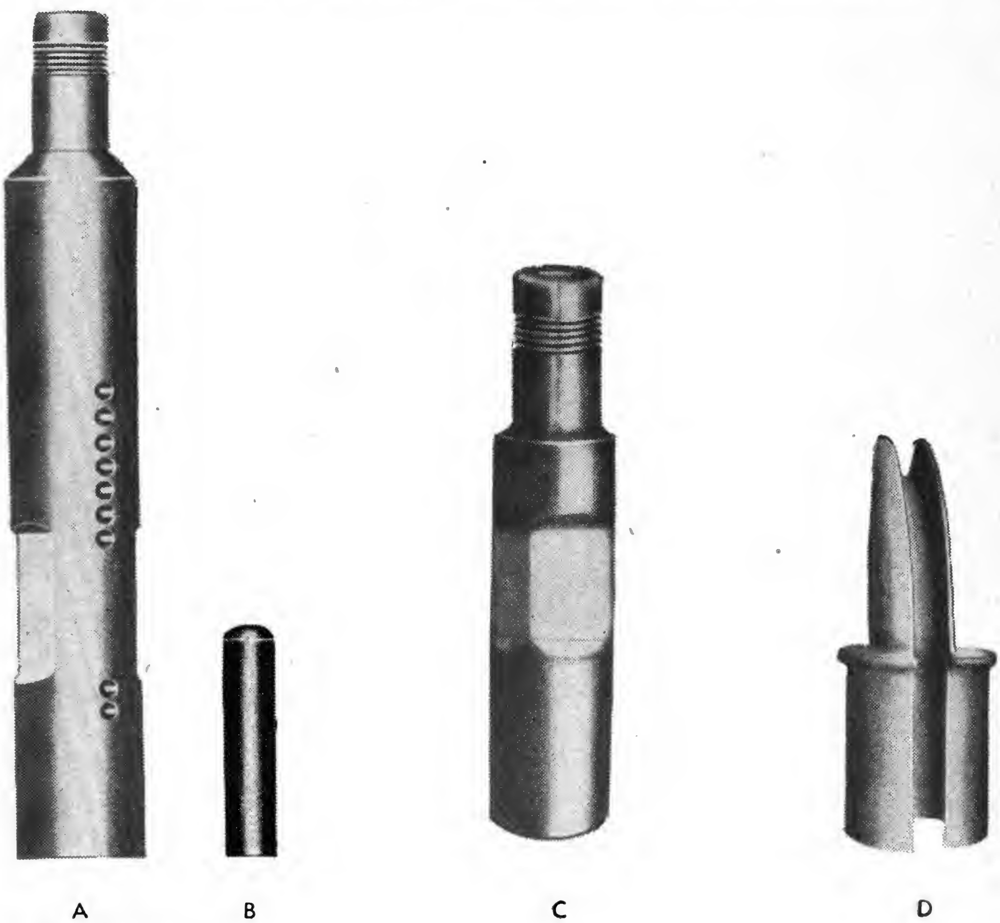
78. DRILLING TOOLS. A complete string of percussion tools is composed of a drill bit, a drill stem, a set of jars, and a rope socket. The tools are subjected to hard service, and special steels are used in their manufacture. They are joined together by box-and-pin screw joints. Special wrenches that fit the squared sections of the tools are used to tighten the joints.

a. Rope saver. The "rope saver" (D, fig. 62) is a wire-line attachment that slips over the neck of the drill-line socket to prevent the line from kinking at this point when the tools are raised from any position other than the vertical. It has a quarter-circle rope groove which the line should follow when the tools are raised. Neglecting to use the "rope saver" may result in a serious kinking of the line at the rope-socket neck.

b. Swivel socket and swivel. (1) The swivel socket (A, fig. 62) is attached to the drilling line, which is attached directly to the swivel (C, fig. 62) inside the socket. The purpose of the swivel socket in drilling is to allow the tool string to spin or turn after each blow. Socket and swivel are one item, and an extra swivel is kept in readiness for resetting the line in the swivel. (Directions for attaching it are given in paragraph 82.) Several holes are drilled in the body of the socket. Those directly above the box end are the flushing holes to keep the joint clear of mud and

drill cuttings. The holes above the wrench square are for flushing the swivel and bore to insure free turning.

(2) This type of wire-rope socket has the advantage over other types for drilling purposes in that it seldom allows the cutting edge of the bit to strike more than one blow in the same place, thus eliminating some of the causes of crooked or flat holes. It also relieves some strain on the wire



A. Swivel socket.
B. Mandrel for swivel socket.
C. Babcock socket.
D. Rope saver.

Figure 62. Rope socket.

rope. As most formations contain abrasive materials that wear the wire rope at the top of the swivel and in the socket neck, frequent inspection is advisable to determine when to reset the drilling line. Under ordinary conditions the line should be reset in the swivel every 50 to 70 hours of drilling.

c. Jars, drilling. **(1)** Drilling jars (fig. 63④) consist of two connecting links, with a pin on the upper link and a box on the lower end.

Their position in the tool string is directly under the swivel socket. Jars are essential when drilling hard rock, where the tools are likely to stick. When drilling without jars special care is taken to drill a full-sized hole so a freshly-dressed bit will not stick. Jars seldom are used when a pipe is being driven. New jars have a 9-inch stroke, which increases as the jar heads wear. It is not safe to use drilling jars after wear has increased their stroke to 11 inches. The severe service required of jars makes it necessary to inspect them daily for cracks or checks.

(2) The jars have no direct drilling function in the tool string. Their purpose is to loosen the tools if they should stick. The tension on the drilling line should keep the jars full extended. When the tool string becomes stuck in the hole, slack off the rope and allow the jar links to open to their full length; then, on the upstroke, the upper section of the jars and socket will jar the tools below. Unless the conditions are unusual, this will loosen the tools, and drilling may be resumed.

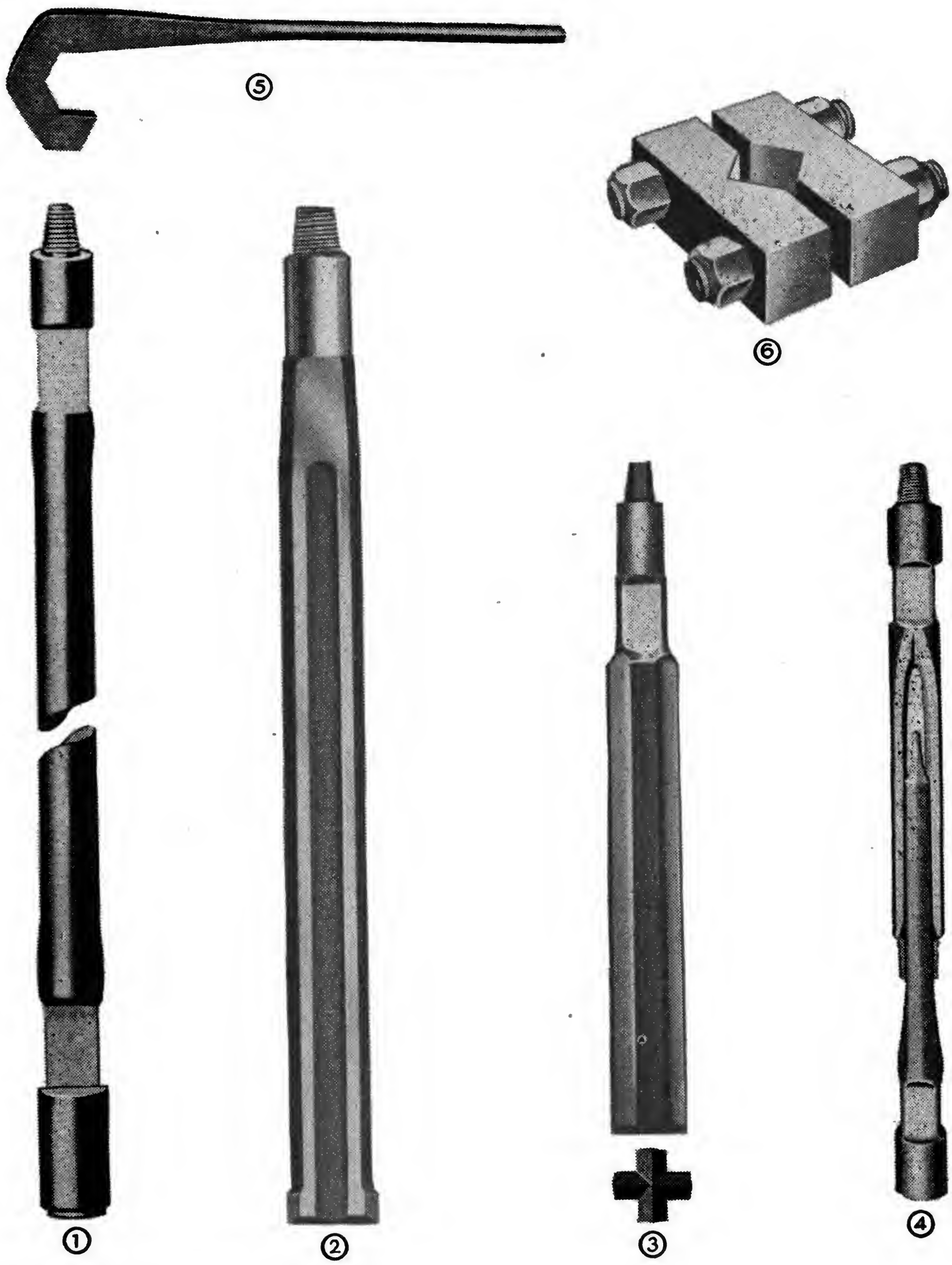
d. Stem, drill. **(1)** The drill stem (fig. 63①) furnishes the necessary weight to the tool string. Two are furnished, one 4¼ inches by 16 feet, and one 4¼ inches by 8 feet. For driving 6-inch pipe to a depth of 75 or 80 feet the 16-foot stem is sufficient. For deeper driving, both stems can be used. Generally both the 16-foot and 8-foot stems are needed in drilling rock to obtain the necessary weight for fast drilling. The stem is always placed below the jars. The stem must not be dropped when unloading from a truck to the ground as a slight bend in it will cause trouble.

(2) Each drill unit has an extra 3-inch pin and box (fig. 63) for replacement purposes. Should a pin or box be cracked, broken, or battered beyond repair a competent welder should cut off the defective joint and weld on a new pin or box with either an electric weld or a blacksmith weld. In welding on a new pin or box end, the axis of the pin or box is lined up exactly with the axis of the stem.

e. Bits. The bit, which does the actual drilling, is the most important part of the string of tools. It consists of the cutting edge, the body, the wrench square, the shank, and the pin. Bits of different shapes are made for different purposes.

(1) Regular-pattern bit. The regular-pattern bit (fig. 63②) is the best all-around bit. The 71 Speed Star rig has both 6- and 8-inch regular-pattern bits. The bit is never allowed to wear down below gauge, especially when drilling in the harder formations, since the diameter of the hole decreases as the gauge of the bit wears down. A fishing job may be necessary and, to accommodate the fishing tools, it is essential that full-gauge holes be drilled. For further information on bits, see **g** below.

(2) Four-wing or star bit. The four-wing or star bit (fig. 63③) sometimes is used for drilling fissured or inclined formations that tend



① *Drill stem.*
② *Regular pattern bit.*
③ *Star or four-wing bit.*
④ *Jars.*
⑤ *Wrench for tightening drive clamps.*
⑥ *Drive clamps.*

Figure 63. Drilling tools.

to deflect the tools from the vertical. The cutting end of this bit has four water channels. The diameter of the body section is only slightly smaller than the gauge size. The four cutting points and the small clearance between blade and hole make this bit particularly effective for reaming and straightening holes. It is not used in regular or ordinary drilling, as it is slow-cutting and difficult to dress. A dressing form is used for dressing it. To be effective this bit must be properly dressed, with sharp corners, and kept at full gauge.

f. Arrangement of forge for heating bits. (1) The most desirable location of the forge is on the blower side of the machine. The forge can be set a few feet from the machine, as determined by the blower hose. The slack tub and anvil block are grouped with the forge. The anvil block is so located that there is space for a man to swing a sledge on either side of the block while dressing bits.

(2) The fire clay furnished with the brick is mixed with water to form a paste and used in laying up the brick in the forge. (Figure 64 suggests a method of building a brick fire pot inside the metal forge.) The fire pot confines the fire so intense heat for bit dressing can be obtained without burning the metal forge. For heating 6- and 8-inch bits a fire pot 12 by 14 inches is recommended. If only 6-inch bits are to be dressed a 12- by 12-inch size is satisfactory. The bricks can extend to the top of the metal forge. The tuyere pipe should project into the forge so the air blast enters the fire pot at the bottom near the center. As the fire-pot walls are built up, the space between the brick and the metal wall is filled with earth, the most desirable kind being clay, or clayey earth. If only sand is available, dampen it somewhat and tamp it. Particular care is used to fill the cracks between the brick with fire clay, or the sand will run through into the fire pot.

(3) With the fire pot completed and the blower connected to the forge, start a fire in the following manner:

(a) Place a 3- or 4-inch diameter stick of wood or pipe upright in the center of the fire pot, with the lower end resting on the opening in the tuyere iron. Pack dampened blacksmith coal firmly around the upright stick until the coal is above the hearth opening of the forge. Jar the upright stick somewhat to loosen it, and withdraw it from the coal. Place kindling material in the opening thus left, light the fire, and start the blower. Add kindling wood and small amounts of coal until a vigorous fire is burning, In a few minutes more coal may be added to the fire while water is sprinkled on the coal body surrounding it. This cokes the coal, and an intense heat is obtained in the forge. When the fire is well started, a bit may be laid in the forge with the cutting edge about 5 inches from the brick wall of the fire pot.

(b) Cover the end of the bit with about three shovelfuls of damp coal. Sprinkle the entire top of the coal with water at frequent intervals to form a coked top over the bit. A long, small diameter poker is necessary to open a small draft hole at each side of the bit and to examine the bit for temperature, as described in **g** below.

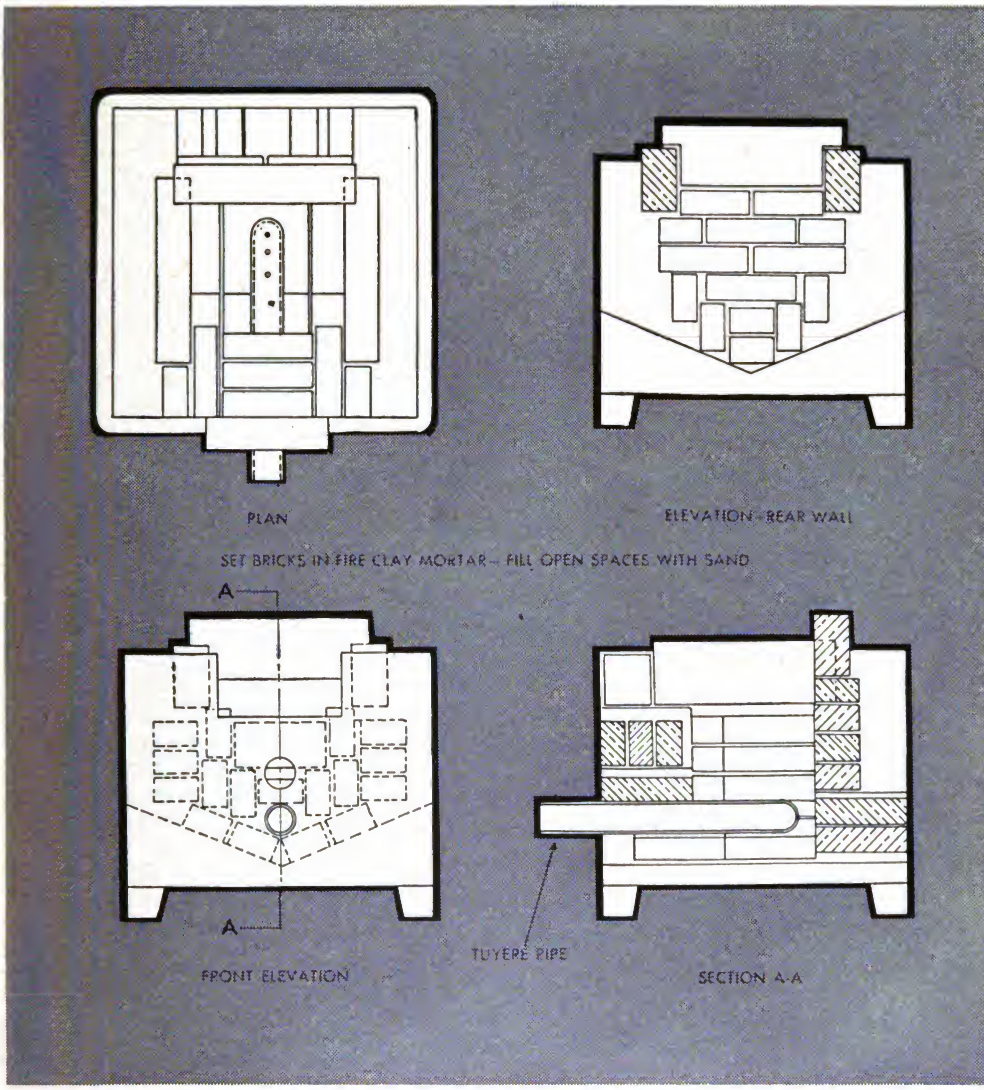


Figure 64. Bit-dressing forge, showing fire brick.

(c) After the bit has turned red on the under side, it is turned in the fire for a more even heating. Lift the pin end of the bit a couple of feet and withdraw the bit slightly from the fire as it is turned. In this way the coked top is maintained over the bit for the entire heating operation. The fire is replenished by feeding into the fire beneath the bit small amounts of coal, or particles of coke from previous heats. When the bit is hot

enough, turn off the air blast and proceed with the dressing. Tempering heat ordinarily can be retained without adding much new fuel.

(4) If the forge is not to be used again for an hour or more, throw three or four shovelfuls of damp coal into the fire pit and dampen the entire coal body to provide coked coal for heating the next bit.

(5) To prepare the forge for another heat, clear the center part down to the tuyere pipe without breaking down the walls of the original coal body. Open up the air holes in the tuyere pipe. Clean cinders from the pipe by removing the hose from the pipe and drawing out the cinders with a small stick or wire. The forge then is ready for starting a new fire.

g. Dressing bits. (1) In dressing bits one of the important operations is to obtain the proper heat. When using coal or coke for heating, the bit is heated to a bright cherry red, being turned in the fire several times to heat both sides thoroughly. Heating a 6-inch bit should take not less than 30 to 45 minutes. The bit is hot enough when the steel seems to be soft when the poker is rubbed along the side of the bit near the end. A little practice will determine the proper time to take the bit from the fire.

(2) In spreading the bit to the gauge, start in the center, using the heel of the sledge to draw the steel. Stand to the side of the bit and, as the blow is struck, pull the sledge in the direction the steel is being worked. Always pull the steel to the point and never to the corners; for, as the points are filled, the steel naturally crowds to the corners. By dressing the bit this way the corners are kept well stocked or thickened.

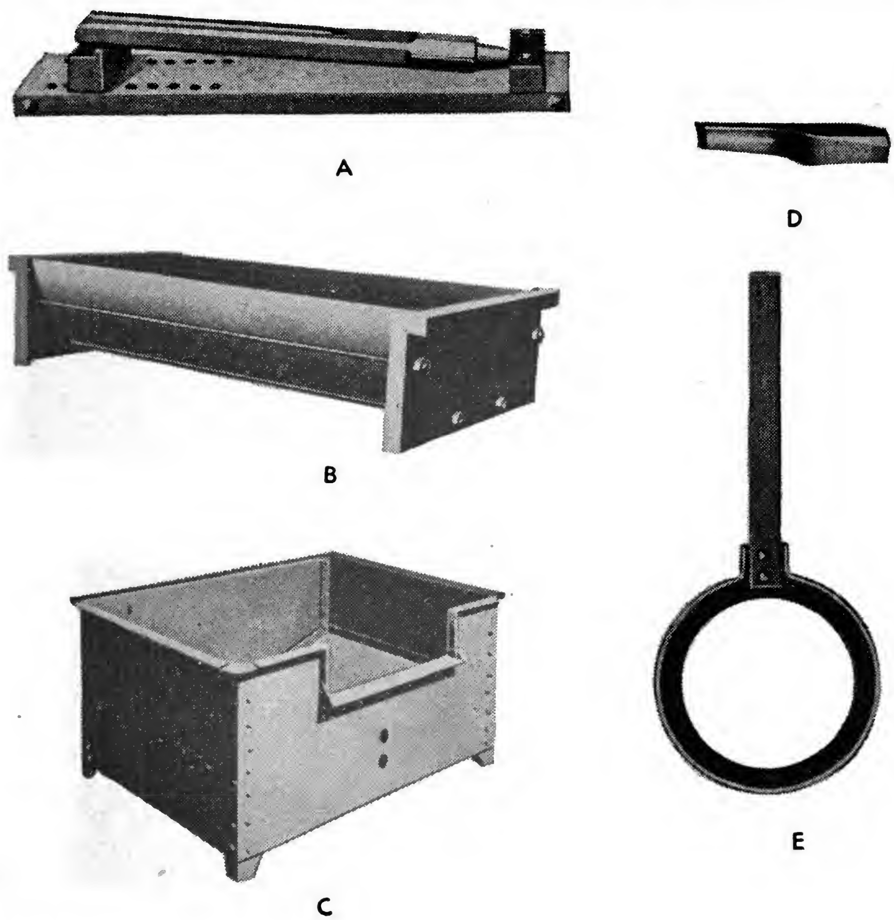
(3) In drilling clay or other soft formations the bevel or face of the bit is kept as short as possible; long bevels cause the bit to stick and drag when the mud becomes thick. In rock, the bevel is kept longer, but too long bevels tend to prevent the bit from turning, thereby causing flat holes.

(4) To drill soft muddy formations, the bit is dressed with a feather edge. This means simply giving the edge of the bit a flare which causes the bit to work freely in the hole, as it cuts a clearance larger than the body of the bit. For use in hard rock the bit is dressed with a "wearing surface." This is obtained by drawing down the steel after it has been spread, giving the shoulders a thickness that acts as a protection and gives more wearing surface for the bit, as the term implies.

(5) A bit works better if the water channels are kept clean by cutting out the steel that spreads into them from repeated dressing. In cutting out a water channel never cut into the body of the bit, as this allows water to enter when the bit is being tempered and causes the bit to crack. Use the peen of the sledge after the bit is spread, driving the steel back into the bit. This also assists in keeping the corners stocked. All the steel cannot be worked out of the water channels in this way, and sometimes it is necessary to cut it away. The best method is to use a regular gouge

(D, 65), as the gouge is shaped like a water channel and will not cut into the body of the bit if properly used. Never attempt to work the bit after the steel cools to a blue tinge. Steel worked at an improper temperature becomes brittle, and peels and cracks off when used. Blacksmith tools are shown in figure 65.

h. Tempering bits. (1) After the bit has been dressed and cooled until



A. Anvil block.
B. Slack tub.
C. Forge.
D. Bit gouge or chipper.
E. Bit gouge.

Figure 65. Blacksmith tools.

all red color has disappeared, it is put back into the forge and heated for tempering. When it has reached a dull red color, remove it from the fire to the slack tub. Pour in sufficient water to reach only as high as the corners of the bit. Leave the bit in water until the red color has practically disappeared. When the bit is placed in the water, the water boils vigorously about its end. In a short time small bubbles start rising around the

end of the bit. These indicate the proper time to remove the bit from the water. When the bubbles are about the size of the large grains of wheat the bit may be removed from the slack tub.

(2) Now file a bright place along the side, from a point a few inches above the corner down to the face of the bit. Different colors will show along the bright, filed edge. The color at the coolest spot, most distant from the face of the bit, is dark blue. Dark blue, light blue, dark straw, and light straw (or copper) are the colors noticed progressively toward the end of the bit. Extreme hardness is indicated by the light straw and colorless portion adjacent to the light straw color. The blue indicates a lesser degree of hardness. In a few minutes the color travels downward toward the face of the bit. When the dark blue has approached or reached the corners, and the straw or copper color has extended down over the face of the bit to the cutting edge, replace the bit in the slack tub and raise the water level over the corners of the bit. An average bit tempered in this way has a hardness suitable for drilling hard rock. As bit steel varies greatly, the proper temper of a bit can be determined only after several trials.

(3) Another method of tempering bits is with a common horseshoe magnet. To use the magnet without burning the fingers, fasten it on a wire handle about 2 feet long. After the bit has been dressed and allowed to cool until no color is visible, replace it in the forge and heat it to a temperature at which the magnet will not be attracted to the bit. Place the bit in the slack tub with water just covering the corners. Some useful points in regard to tempering bits follow:

(a) A bit dressed for the first time is heated to a dull cherry red; afterward it can be heated to a full cherry red, or, if a great deal of stoving is to be done, to a bright cherry red. It never is heated higher than a bright cherry red. Starry-looking sparks called "yellow jackets" coming from the fire indicate the steel is being burned and the bit soon will be ruined.

(b) Sunlight makes judgment of the colors difficult. When the bit is examined in a bright light, the temperature is higher than it appears.

(c) Observe the action of the bit after the first tempering, and increase or decrease the hardness of the steel until the proper temper has been determined by actual use; then endeavor to reach the same point each time.

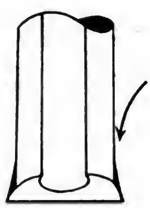
(d) Do not temper on a falling heat. Always raise the heat to temper. For drilling shale the temper need not be drawn. When the bit has cooled properly after dressing, replace it in the forge and raise the temperature to a dull red. Then cool the bit in the slack tub.

(e) Keep the water in the slack tub clean.

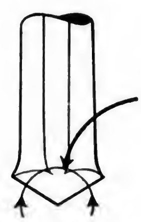
i. Suggestions for shaping bits. **(1)** Eight important factors affect

the design and method of dressing a drill bit to suit the formation being drilled and to obtain most effective penetration. These are:

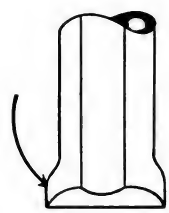
(a) Angle of clearance.
(b) Angle of penetration.
(c) Wearing surface.
(d) Reaming edge.
(e) Area of crushing face.
(f) Area of water channel.
(g) Contour of penetrating edge.
(h) Cross section of drill bit.



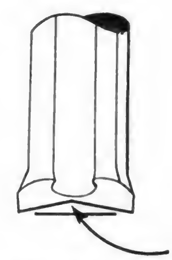
The Angle of Clearance is the taper on the outside or reaming edges. Drawing shows drill bit having wide **angle of clearance** and no **wearing surface.** Arrow points to **angle of clearance.**



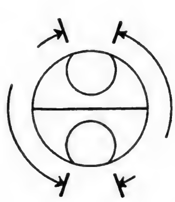
The Angle of Penetration is the bevel on the cutting edge which penetrates or breaks up the material in the bottom of the drill hole. Drawing shows drill bit having a **penetrating angle** of 120°. Arrow points to the **angle of penetration.**



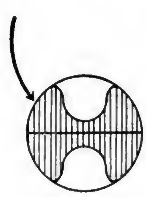
The Wearing Surface is the area which has no clearance and is in actual contact with the wall of the drill hole. This drill bit has a large area of **wearing surface** and no **angle of clearance.** Arrow points to **wearing surface.**



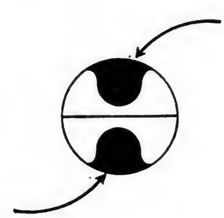
The Contour of Penetrating Edge on a drill bit may be **concaved,** straight or convex, and the degree of **contour** is measured by the change in angle from a square line across the bottom of the bit. The drawing shows a **concaved penetrating** edge.



The Reaming Edge is the outside edge of the bit and is measured as a part of the full circumference. Drawing shows drill bit having 80 per cent **reaming edge** — 40 per cent **reaming edge** on either side of the water courses.



The Crushing Face is the area of surface on the bottom of the bit and is compared by measuring its percentage of the total area of the drill hole. Arrow points to **crushing face** —the shaded portion of the drawing. **Water courses** shown in white.



The Water Course is that portion of the hole which is not filled by the bit and through which the water or cuttings must pass when the bit is moved up or down in the hole. Arrows point to water courses, in black on this drawing.

The Cross Section of a drill bit is a size of the body at a point back from the end when it is not upset. Arrow points to **cross section.** The drawing shows the cross section of a drill bit back a few inches from the cutting edge.

Figure 66. Suggestions for shaping drill bits.

(2) The following figures illustrate each of the eight important features of a drill bit. With a careful study of operations usually it is possible to arrive at a shape of bit that gives maximum drilling speed, at the same time increasing the footage that can be drilled between dressings and decreasing the time and labor required to keep the bits in proper condition. (See fig. 66.)

j. Function of drill bit. A drill bit has four important functions. These are penetrating, crushing, reaming, and mixing. The character of the formation to be drilled always determines which of the four functions is most important; for example—

(1) Drilling in hard limestone. In hard limestone the most important function is penetration. If the rock has a high silica content it will be abrasive, and in this case the function of reaming must also be considered. Hard solid limestone that has no vertical seams or open fissures to deflect the drill hole is drilled with a bit having a sharp angle of penetration. The contour of the penetrating edge is slightly concave and if the formation is not abrasive a wide angle of clearance is used. If seams or fissures are encountered the penetrating angle is greatly increased, making the bit blunt, which brings the corners and reaming edges nearer to the penetrating edge where the reaming edges can cut into the slanting side of a seam and carry the hole down without deflection. Should the size of the bit be worn rapidly and the diameter of the hole reduced until difficulty is encountered when a fresh bit is run into it, it is necessary to reduce the angle of clearance to allow the bit's wearing surface to resist the abrasion.

(2) Drilling in soft limestone. Soft limestone requires special attention to the crushing function, and if the limestone contains a noticeable amount of clay some attention is given to mixing. Soft limestone with open seams, fissures, and hard spots requires a drill bit with the maximum reaming edge, a liberal angle of clearance, and ample crushing-face area. The angle of the penetrating edge should be flat, but its contour should be concaved about 3/8 inch on a 6-inch bit.

(3) Drilling in quartzite or granite. Quartzite and granite usually are hard and abrasive; therefore the most important functions of the drill bit are to penetrate and to ream and no attention need be given to crushing and mixing. Granite, quartzite, or traprock with vertical seams and fissures require a drill bit with a wide angle of penetration which forms a thick, heavy cutting edge to withstand the impact of heavy tools on hard rock. The reaming edges are kept out to full gauge size and not more than 1/2-inch back of the penetrating or cutting edge. The contour of the cutting edge is slightly concaved. Most important is the wearing surface, which is as straight as possible, allowing little or no angle of clearance. The cross section or body size of the bit should be large, to guide the tools in the hole and to prevent offset when fissures are encountered.

(4) Drilling in soft formations. Shale, clay, and soft limestone require special attention to mixing, and in many cases it is necessary to retard penetration in order to secure maximum mixing results. These formations require a drill bit with entirely different features, to perform the important function of mixing. Little if any penetrating angle is

necessary. The greatest possible angle of clearance is used, and the cross section or body size of the bit is small. A large area of crushing face is given to the bit for the purpose of retarding penetration and at the same time packing the material in the bottom of the hole to prevent the tools from diving and sticking . To analyze any drilling problem it is necessary to know the physical character of the formation. The most important function of the drill bit then can be determined, and its features worked out to give the best results.

k. Tool joints. (1) A tool joint (fig. 67) consists of a tapered pin and conforming box. All tools furnished with the No. 71 Speed Star are fitted with 2- by 3-inch American Petroleum Institute joints, having 4¼-inch pin collar, 4⅜-inch box collar, and 3¼-inch wrench square. Both the swivel and the babcock sockets have 2⅜-inch neck.

(2) Joints are machined to close clearances. Good care and careful handling are essential to keep joints in proper condition. They should

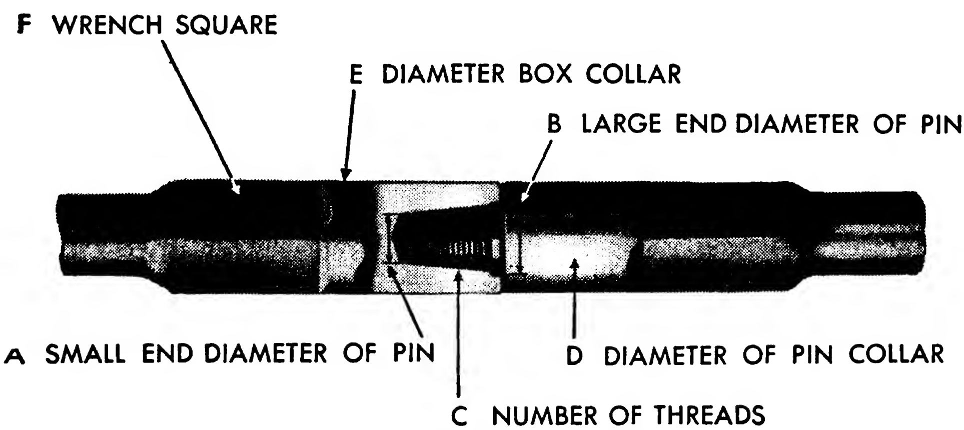


Figure 67. Details of tool joint.

be kept clean and free of rust. If the shoulder (the friction face on the ends of the pin and box collars) become rusty or rough, it is polished with a smooth-grained stone or emery cloth until perfectly smooth. Shoulders are polished evenly so as to avoid depression in their faces.

(3) Do not attempt to make up a joint if the threads are battered. If threads are not too bad, they may be filed off to pitch with a fine, three-cornered file. Otherwise, have them re-turned.

(4) A tool joint must be watertight. If a leak occurs, inspect shoulders for depressions, and collars for cracks.

(5) When tools are not in use keep all joints well lubricated, and covered with the protector supplied for each joint.

l. Wrenches, tool. A set of two tool wrenches (fig. 68), one right-hand and one left-hand, is furnished with each drilling unit. Jaw openings are 3¼ inches, to conform with wrench squares on drilling and fishing

tools. The right-hand wrench is shown above and the left-hand wrench below. To tighten a joint, place the left-hand wrench on the bottom square and the right-hand wrench on top; reverse for loosening.

m. Wrench bar and chain. The wrench bar (fig. 68) is used with tool wrenches. To tighten, the top chain goes to the right-hand wrench and the bottom chain to the left-hand wrench; reverse for loosening. With chains placed in the two bottom holes of the wrench bar one man

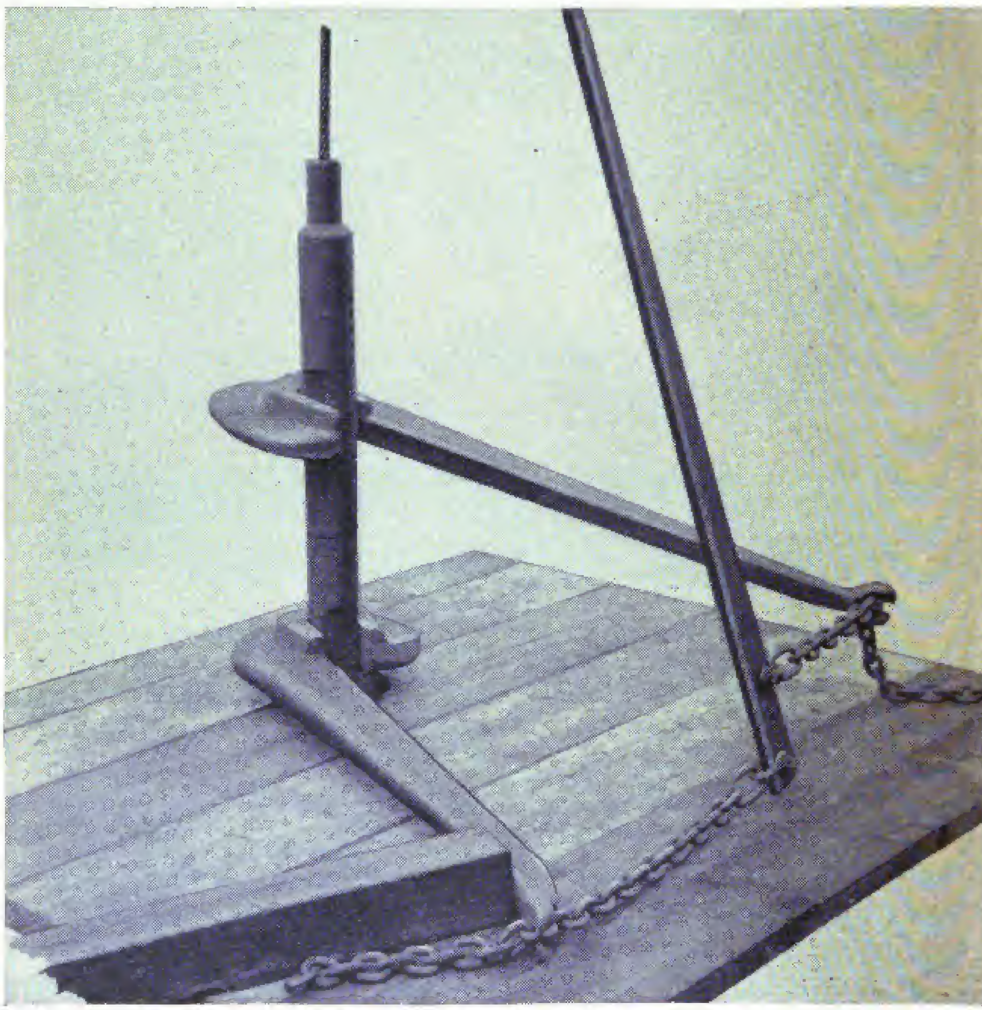


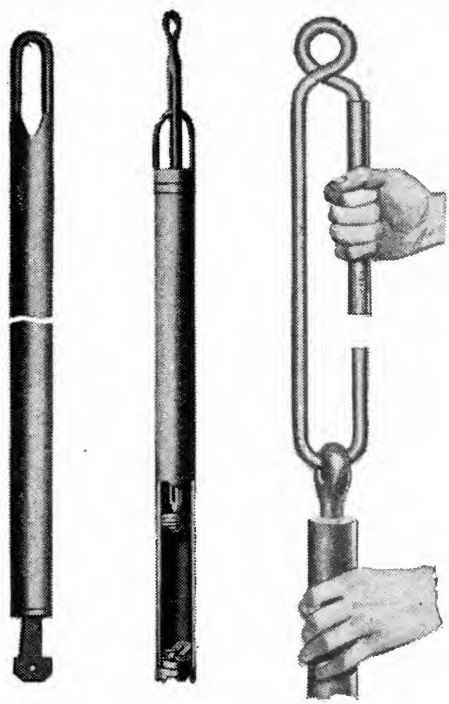
Figure 68. Tool wrenches with wrench bar and chain.

of normal strength can set up a joint, but it takes two men to break it. Joints must not be subjected to overstrain in tightening. They must be tight, but not to the point where more than two men are needed to loosen a joint.

n. Bailers. When a percussion drilling machine is used, drill cuttings are removed from the well by a bailer or a vacuum sand pump.

(1) Dart-valve bailer. The dart-valve bailer ((1), fig. 69) is used in most bailing operations. The dart-valve opens when it contacts the cuttings at the bottom of the hole. A slight up and down motion of the bailer tends to draw the mud or cuttings into it. When the bailer is withdrawn, the dart valve automatically closes, trapping the contents in the bailer. In raising and lowering the bailer in the hole some indications as to the condition of the hole may be noted. If the cuttings or sand and gravel are too heavy, or in too great quantity, the sand pump is used.

(2) Sand pump. The sand pump ((2), fig. 69) is used in sand and gravel where the dart-valve bailer will not pick up the materials. It is



1   2   3

1. Dart-valve bailer.
2. Sand pump.
3. Bailer link.

Figure 69. Bailers.

made of tubing with a hinge flap valve and a plunger that works inside the barrel. The sand line is attached to the top of the plunger rod. The sand pump is lowered to the bottom of the hole, allowing the plunger to travel to the bottom of the sand pump. When the plunger is raised, the material is sucked into the bailer. When the plunger reaches the top of the sand pump bail, it raises the pump and the hinge valve closes. To empty it, up-end the sand pump in the trough by swinging the pump on the plunger rod. Some sand pumps have a hinged valve on the lower end that may be tripped for emptying the contents.

o. Link, bailer. The "bailer link" ((3), fig. 69) is made with an opening on one side which is closed and opened by a sliding sleeve. When the link is attached to the sand line in a vertical position the sleeve falls and the opening is closed. By pushing up the sleeve the line and link can be detached quickly from one bailer and transferred to another, or to the jar bumper.

79. FISHING TOOLS.

a. Use. (1) All fishing jobs are comparatively simple until some mistake is made, complicating them to a degree that makes recovery of the lost tools or pipe difficult if not impossible. The possibility of complications is such that it is better to do nothing at all than to run a weak or unsuitable fishing tool into the hole.

(2) Present Corps of Engineers fishing-tool equipment consists of only a few of the primary tools, but even when a well-stocked warehouse is convenient often it will be found necessary to fabricate a tool or alter existing tools to fit special conditions.

(3) Never run any fishing tool into the holes without the jars installed between the fishing tool and the sinker bar or drill stem. The weight of the sinker bar or drill stem *above* the jars is the effective force in jarring loose tools stuck in the hole.

(4) Examine lines for broken and worn places.

(5) Keep a careful record of the depth of the hole and of the over-all length of the drilling tools, as this information is essential for fishing.

(6) Since the fishing tool may let go of the lost tools while they are being pulled from a deep, dry hole, the danger of damage to the tools can be minimized by filling the hole with water to a depth of 175 to 200 feet before pulling the tools. The water cushions their fall.

(7) Run an impression block to see if lost tools are in proper position for fishing tools to take hold.

(8) A short stroke on the crank arm gives best control of fishing tools. Use it until a longer stroke seems desirable.

(9) Sockets having slips may be run the first time without the slips, to see if the hole will let them pass through, whether the socket will go over the lost tool, and what hitch is required.

(10) Impression block. (a) Lost tools are more successfully fished for when their position in the hole is definitely known. A tool may lean to the side of the hole, or into a caved area, in such a way that a fishing socket will not take hold. The top of the tools may be covered with cave material. A pin or rope socket neck may have become changed in shape and size during fishing operations. Such conditions can be determined by means of an impression block.

(b) The material required for an impression block is a rounded piece of wood, 3 feet long, 7 3/4 inches in diameter for an 8-inch hole or 5 3/4 inches in diameter for a 6-inch hole; one piece of sheet metal 7 by 24 inches; one bolt, 5/8 by 4 1/2 inches; 2 pounds of 10-penny nails; and 10 bars of yellow soap or 5 pounds of parawax (see fig. 70).

(c) One end of the wood block is reduced in size to that of the outside diameter of the bailer used in the hole. This end is slotted for attachment to the dart of the bailer by a bolt extending through the slotted portion of the wood block and the bailer dart. The sheet metal is nailed around the solid end of the wood block so it extends about 3 inches beyond the end of the wood. A number of nails are driven part way into the end of the block, surrounded by the sheet metal. Warm the soap until it becomes somewhat plastic, and fill the hollow end of the block formed by the projecting edge of sheet metal. The nail heads help to hold the soap in the block.

(d) Without the block, lower the bailer into the hole and find the point of pick-up. Mark this point on the sand line so it can be easily recognized. This mark will be a guide when setting the impression block on the lost tools. Make allowance on the bailer tube for the length of the block.

(e) Attach the block to the bailer dart and lower it into the hole. Allow the bailer to set down firmly, but not too hard. Pick up the bailer gently and with moderate speed, and pull it out of the hole without letting it down a second time. Carefully remove the block from the bailer and look for impressions in the soap or wax.

b. Corps of Engineers' tools. The present Corps of Engineers' fishing tools and their primary uses are as follows:

(1) Babcock socket. For fishing work the Babcock socket (fig. 62(3)) is used instead of the regular drilling or swivel socket. For a special fishing job, the swivel socket may be desirable, but for most fishing jobs it is not practical, because it allows the drilling line to change its over-all length. Changing the length of the drill line even 1 inch may prevent a fishing tool from taking hold of a lost tool, or result in breaking the hold at the wrong time The Babcock socket may be attached to the drilling line by one of several methods described in paragraph 82.

(2) Fishing jars. Fishing jars are of the same construction as drilling jars, except for a much longer stroke. Their place in the string of tools is between the 10-foot fishing stem and the fishing tool. Thus, the blow of the stem is imparted to the fishing tool. A certain amount of up-jarring can be done with short-stroke jars, but they give the driller small chance to control his jarring operation. In case the object being jarred moves upward a short distance the jars will start hitting up and down or,

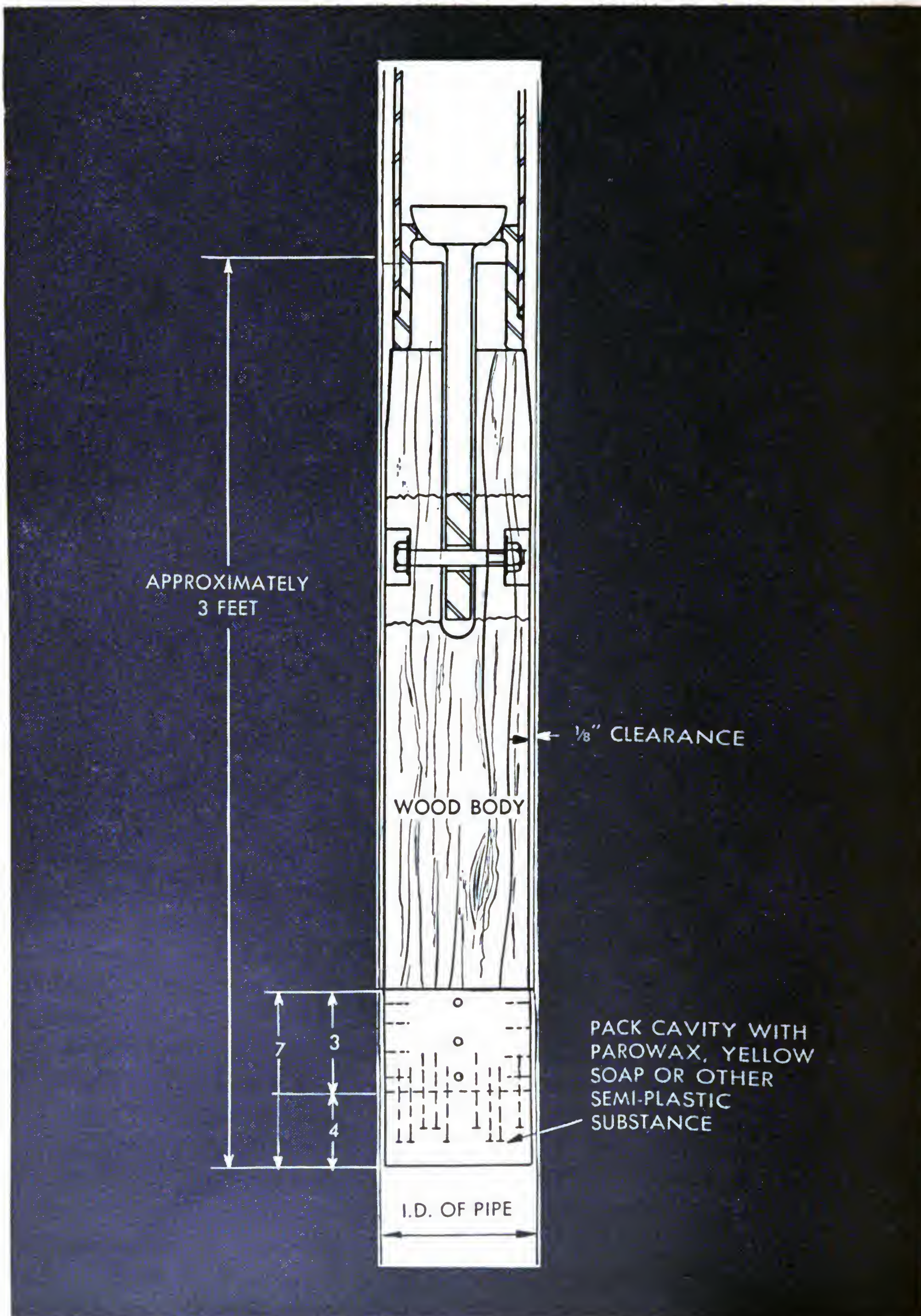
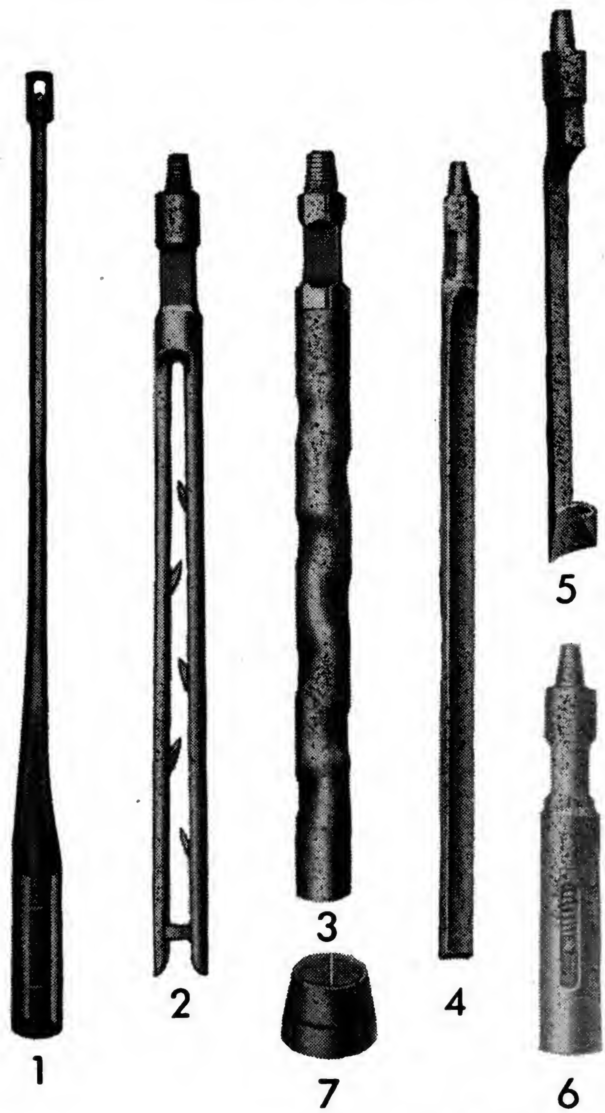


Figure 70. Impression block.

in other words, "both ways." Hitting "both ways" is almost sure to break a hold. Sometimes it requires days to get the hold, and it may be impossible to repeat it. Therefore it is unwise to attempt a fishing job



1. *Jar bumper.*
2. *Two-ring rope grab with latch-jack bottom.*
3. *Corrugated friction socket.*
4. *Spud.*
5. *Wall hook.*
6. *Combination socket.*
7. *Slips for combination socket.*

Figure 71. Fishing tools.

without regular fishing jars. In down-jarring, no effective blow can be delivered without long-stroke fishing jars.

(3) Jar bumper. The jar bumper ((1), fig. 71) is used for loosening drilling tools stuck in the hole.

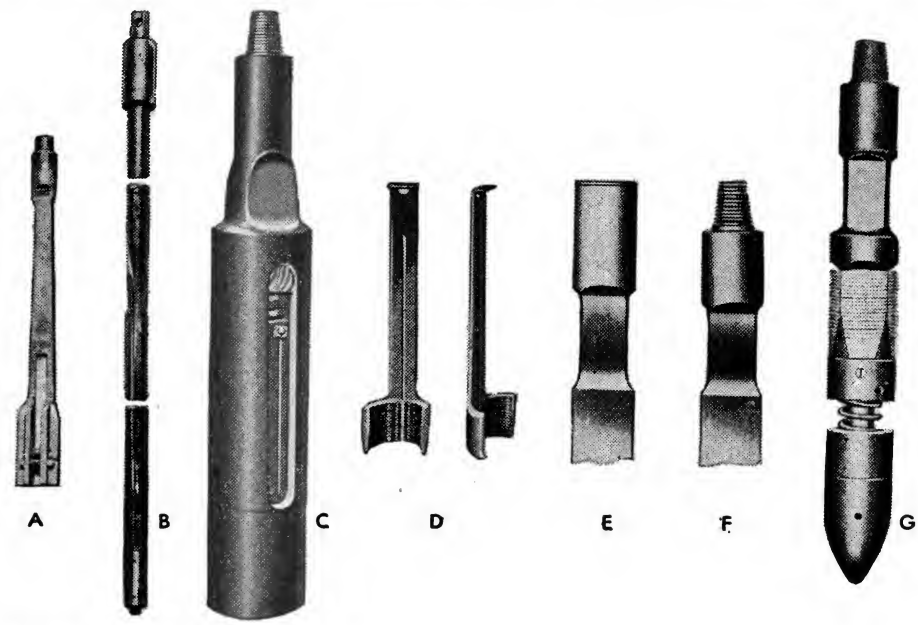
(a) When the tools become stuck while drilling without jars, take a hard strain on the drilling line with the machine. Pick up the jar bumper with the bailing line and fasten it on the drilling cable with the bolt provided for that purpose; then run the jar bumper down carefully until it hits the top of the tools. If it works freely without binding or sticking on top of the tools, pick it up about 15 feet and let it drop on the tools, meanwhile keeping a hard strain on the drilling line. A few hard blows usually will suffice, except when the tools are deeply buried in sand or cavings.

(b) When boulders or other debris fall in the hole and wedge a normal string of tools so tightly against the wall of the hole that the jars become locked, usually they can be loosened by the same procedure as in the **(a)** above, except that only enough strain is held on the drilling cable to prevent excessive slack in the hole. Hold the bull reel brake lightly, so the action of the jar bumper striking the tools drives the jar links together. When the jar links have been driven together, throw in the spudder beam clutch and jerk or pull on the drilling cable until the jar links are extended. A few repetitions usually will loosen the jars so they can be used to free the tools.

(4) Friction socket. When a bit is unscrewed or broken off in the hole, a friction socket ((3), fig. 71) is used first for its attempted recovery. No serious attempt should be made to recover the lost tool while running this socket for the first time. Set the fishing tools down on top of the lost tool and drive down lightly with the jars. Then, pull the fishing tools to the surface and examine the marks and abrasions on the socket. If they show the socket went over the end of the tool, run the fishing tools back in the hole and drive the socket far enough over the lost tool so it takes a friction hold sufficient for recovery. When the marks on the friction socket show it went down beside the lost tool, no further effort should be made with this tool, as its use will only drive the tool deeper into the wall. A spud then is used to straighten the lost tool in the hole. Alternate use of the spud and the friction socket often is effective.

(5) Full-circle slip socket. (a) The full-circle slip socket (C, fig. 72) has hardened steel slips, so it will take a firmer hold on the lost tool than the ordinary friction socket. The slips are in two sizes, 4⅜ inches for catching a broken drill stem box, and 4¼ inches for catching the pin collar of a bit or a drill stem, or the jars. Its use is desirable when the tools to be recovered are "frozen" in the hole by cavings or drill cuttings. The slips are not used with the socket until after it has been run to determine whether or not the socket goes over the lost tool; otherwise, the slips are likely to be lost or badly damaged. After catching hold of the lost tool with this tool, care is taken to avoid hitting down on it with the jars, as this so breaks or damages the slips that their hold on the tool is broken.

(b) The split design of the slips permits four slips to be held in their proper position in the socket by two reins. The reins are fastened together at the top end by a bolt. A short distance below this bolt a pin passes across the body of the socket. The purpose of the pin is twofold: it prevents the slips from being pulled out of the socket and lost in the hole, in case of a broken hole; and it prevents the socket from going over the lost tool too deeply and damaging the slip assembly and tension spring. The pin will not stand much jarring; it is important, therefore, to flag the line to indicate the top of the lost tools and to keep careful check of meas-



A. Wire-rope knife.
B. Sinker jars for wire-rope knife.
C. Full-circle socket.
D. Slips for full-circle socket.
E. Box joint for welding on tools.
F. Pin joint for welding on tools.
G. Trip-casing spear.

Figure 72. Fishing tools.

urements when taking the hold. It may or may not be necessary to jar down to set the slips. Stop the spudder when pulling up the line, to determine whether a hold has been secured. Do not jar both ways unless the lost tool cannot be loosened otherwise and it is desired to break the hold, as considerable damage may result to both slips and socket.

(6) Combination socket. (a) The combination socket ((6), fig. 71) is made to catch the neck of the rope socket or pin of any bit or tool which becomes unscrewed in the hole. It has two sets of slips, one to catch the 2- by 3- by 7-inch American Petroleum Institute tool

joint pin and one to catch the 2¾-inch rope socket neck. Use the correct slip for each operation. This is probably the most positive of all percussion fishing tool equipment. Once a firm grip is established on the lost tool, nothing can shake it loose. For this reason it is used only when there is no doubt that the lost tool can be "jarred loose" by the weight of the fishing tools used.

(b) To use the socket, clean and lubricate it inside, then set the joint into the box of the fishing jars. Place the wrist pins in one of the shorter crank-arm positions. Dismantle socket and make a trial run into the hole, without slips. This will determine whether the hole is full size down to the lost tools, whether the socket will go over the lost tools, and the proper hitch. These facts being known, assemble the socket by inserting each half of the split sleeve into the socket through the slots inside the socket, placing the sleeve so the end with a hole is at the pin end of the socket. Pass the coil spring through the bottom of the socket, and telescope the spring and split sleeve into the upper part of the socket body. Clean, polish, and lubricate the rear side of the three slips and place them, tapered end down, in proper position in the bottom of the socket. Hold the spring in the top of the socket and drop the split sleeve down on the slips. Insert the ring through the side slot into the inside of the socket, and fasten both parts of the split sleeve and ring securely together with the bolt. Drop the spring on top of the sleeve ring, and insert a wooden block in the space between the body of the socket and the spring. The wooden block should be of a size that will compress the spring enough to exert firm pressure against the slips.

(c) Run the socket into the hole and set it down on top of the lost tools. Without picking up the socket, jar down with several solid blows of the fishing tools. Stop the spudder and pull up the drilling line to determine whether a hold has been secured on the lost tools. If the tools cannot be pulled, start the spudder and jar up, taking up line with the bull reel as the tools move. When all the tools swing free, the entire load may be pulled out. If the lost tools do not come free and it is desired to pull out the fishing tools, break the hold of the combination socket by jarring "both ways;" or, in other words, allowing the jars to hit at both the top and the bottom of each stroke. This operation is rather uncertain. It may be accomplished in a few minutes with no damage to tools; or it may require hours, and result in broken and lost slips as well as damage to the body of socket and to the pin or neck being fished for.

(7) Spud. The spud ((4), fig. 71) is an effective tool for straightening, in the hole, bits or tools that have been pushed into the wall in such a way that it is not possible to get a socket over them. The proper way to use this tool is to set it down alongside the lost tools and then run the machine

so that with each stroke of the beams the fishing jars hit both up and down. After 20 to 30 minutes the spud is removed and a trial run made with the socket. If this method is not successful in straightening up the tools, try to set the end of the spud on top of them. With patience, usually this can be done. When the end of the spud is set on the tools, drive it down its full length between the wall of the hole and the tools. Before removing the spud from this position, run the tools so the jars strike both up and down. This has a tendency to open up a space between the top of the tools and the wall, and adds greatly to the chances of success when the next attempt is made with the socket. To loosen a stuck bit or tool it is not essential that the spud turn in the hole. Heat the end of the spud in the tool-dresser's fire, and dress it with a sledge so the end is thicker than the body of the blade. Then the spud will cut its own clearance, and run freely in the hole. After dressing, temper the spud in a shallow tempering bath.

(8) Wall hook. When the top of the tools to be straightened up has fallen into a cave in the side of the hole, the wall hook is the most practical fishing tool for realigning them so the socket can be used ((5), fig. 71). This should be run down beside the tools so the hook can be worked in behind them. This usually can be done by running the tools at moderate speed, allowing the jars to hit both up and down, and gradually working up to the top of the tools. This operation requires considerable patience, and is not always successful. Make several trials before abandoning the attempt.

(9) Two-prong rope grab with latch-jack bottom ((2), fig.71). **(a)** This tool is used when the drilling line or sand line breaks and leaves the bailer or drilling tools in the hole, with the line on top of the lost tools.

(b) Measure the line from the top of the hole to the broken end and compare it with the depth of the hole, remembering to subtract the length of the lost tools to determine how much line is on top of the tools.

(c) In the case of a bailer with a relatively small amount of lost line, the rope grab may reach down through several coils of wire, so the latch-jack bottom can catch on the bail of the bailer.

(d) When running a 6-inch grab in an 8-inch hole, it must not be run too far past the end of the line, allowing the loose end of the line to foul the fishing stem and jars, as this can result in losing the fishing tools. A practical preventive is to take a length of ¾- or 1-inch manila rope and pass it through the crotch of the rope grab, back and forth around each prong, nailing each round to the previous round so as to make an enlargement or muff, that will prevent the loose end of the cable from getting up around the fishing jars. This muff is put on so it will not slide up over the grab, and must be of such size as to pass freely through the bit gauge

by which are dressed the bits that drill the hole. The grab is run carefully so the line does not become wadded in the hole in such a way that the grab cannot penetrate into the mass of wire.

(e) If a hold is secured on the wire, and the lost tools are lifted off the bottom of the hole, stop when 15 or 20 feet up and allow the brake to give a short, quick slip to test the hold. If the hold is insecure it will be broken, but no damage will result to the tools by the short fall back to the bottom; whereas, a longer fall might damage them. As the fishing tools are pulled up, the driller will know by the load whether the lost tools are coming along. In either case, pull out. If the hold has broken, there may be some strands of broken wire on the grab, which should be removed from the hole rather than left on top of the lost tools.

(f) As the grab comes out of the hole, be careful that the broken ends of the cable do not slip off its prongs. Do not pull the grab completely out of the hole; stop as soon as the broken wires appear, and tie them to each other and to the prongs of the grab so the loose ends cannot unfold and break the hold. Make the tie carefully, as severe injury to the hands can result from a slip while tying. The tie itself does not carry the load but binds and holds the broken wires in position as the grab is pulled out.

(10) Casing spear. The 6-inch casing spear (G, fig. 72) is an effective tool for pulling pipe, especially when used in conjunction with the jacks and the pulling ring. The chief precaution in using the spear is to unseat it after every 2 hours of operation, and to reset it in a slightly higher position. Continued jarring with the spear seated in one place distorts the pipe to such an extent it is impossible to unseat the spear.

(11) Wire-rope knife. The wire-rope knife (A, fig. 72) and sinker jars (B, fig. 72) are used for cutting the wire line if the tools become stuck in the hole. The knife is lowered onto the drilling line with the sand line and, when the knife strikes the rope socket, it is operated by jerking up with the sinker jar. If the bailer becomes stuck, the wire-rope knife is run in with the drilling line.

80. DRIVE PIPE AND EQUIPMENT.

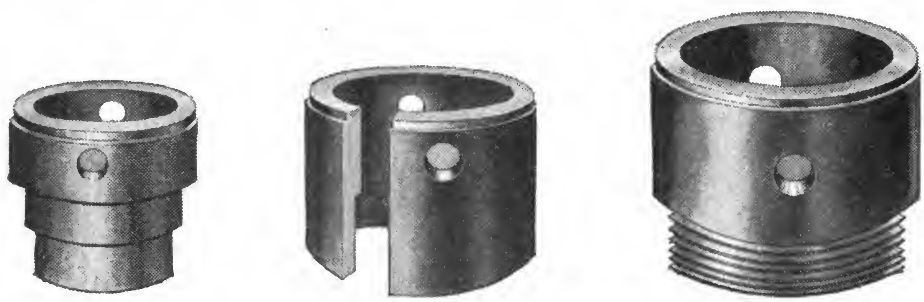
a. Description of pipe. Standard Corps of Engineers' drive pipe is furnished in 6- and 8-inch sizes, with the following dimensions:

Size (inches)	Weight per foot	Diameters (inches)		Couplings (inches)		Threads	Taper
		O. D.	I. D.	Length	O. D.	Per inch	Inches
6	19.45	6.625	6.065	5⅛	7.482	8	3/16
8	25.55	8.625	8.071	6⅛	9.596	8	3/16

In making up drive pipe the two ends of the pipe meet in the center of the coupling, making a butt joint. Drive-pipe threads are not interchangeable with standard pipe threads.

b. Drive clamps. Drive clamps ((6), fig. 63) used in driving casing or pipe, are attached with bolts and nuts to the square of the drill stem (described under drilling tools) at the pin end. When driving, the clamps strike the drive head or coupling at the top of the casing. The stem serves as a guide through the head and furnishes the necessary weight for driving.

c. Drive heads. Drive heads are used at the top end of the upper joint of pipe to protect the threads from the driving blows of the drive clamps. They are made in the following types: outside drop, inside drop, and screw (fig. 73). The drive heads are put on the tool spring by



1 2 3

1. *Inside drop head.*
2. *Outside drop head.*
3. *Screw type drive head.*

Figure 73. Drive heads.

unscrewing the bit, slipping the drive head over the drilling stem, and making up the joint again. When using the screw type drive head be sure the drive head is unscrewed from the pipe coupling before pulling the tools from the hole.

(1) Outside drop drive head. During the driving operation the outside drop drive head (fig. 73) is held in place on the pipe by a "skirt" which extends down about 12 inches around the top of the drive pipe. This drive head is convenient to use and gives good service except under hard driving conditions, when it tends to spring or pump off the end of the pipe with each stroke.

(2) Inside drop drive head. During the driving operation the inside drop drive head ((1), fig. 73) is held in place by the lower end, which fits inside the pipe.

(3) Screw type drive head. The screw type drive head ((3), fig. 73) is equipped with threads, and screws into the drive-pipe coupling far enough for the head to shoulder against the top of the coupling. This

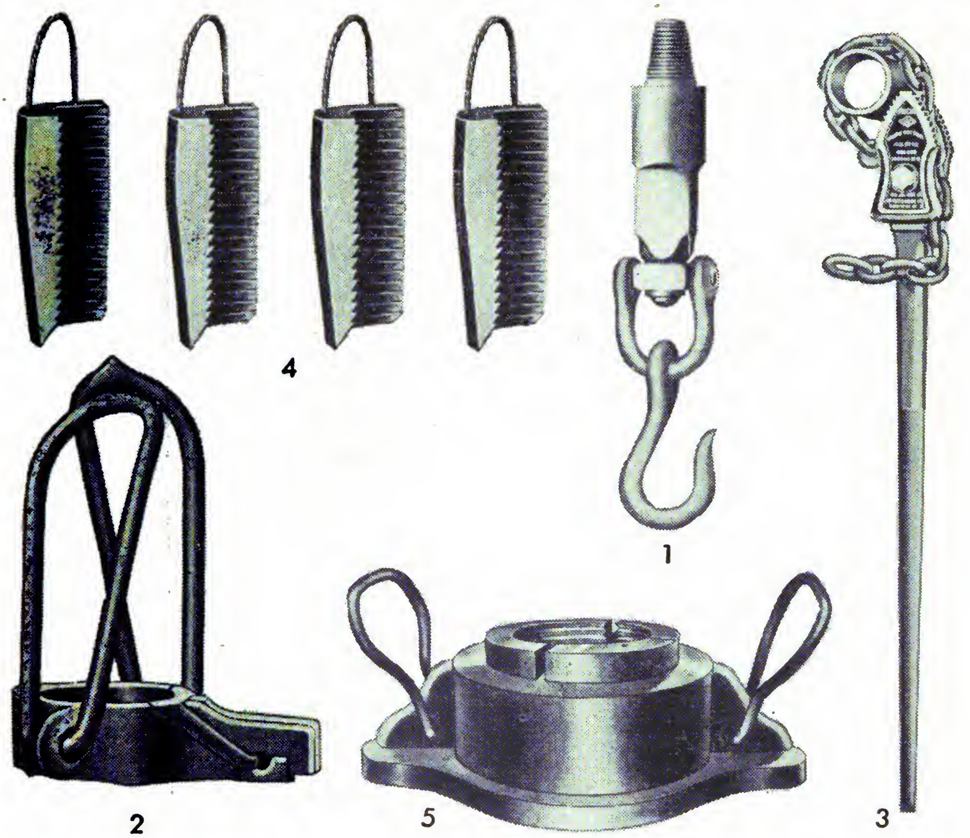
type of head when properly screwed in and seated against the coupling is practically an integral part of the drive pipe, and is almost essential for hard driving—4 feet or less per hour.

d. Drive shoes. In driving pipe or casing, a drive shoe (fig. 73) always is attached to the lower end of the pipe to prevent the pipe from collapsing or crumpling in formations where it is subject to damage by driving. Drive shoes are threaded to fit the pipe or casing, and the inside diameter of the shoe below the shoulder is the same as the inside diameter of the

Figure 74. Drive shoe.

pipe. These shoes are forged of high carbon steel, without welds, and are hardened at the cutting edge to stand hard driving. The drive shoe always is screwed up tight, and the inside shoulder of the shoe butts against the end of the pipe. Both 6- and 8-inch shoes are furnished with Corps of Engineers' percussion-drilling machines. The 6-inch drive shoes are 6 inches long and weigh 22 pounds each. The 8-inch drive shoes are 8 inches long and weigh 42 pounds each.

e. Elevators. Casing elevators ((2), fig. 75) are used for raising or lowering tubing, casing, or drive pipe. One "Fairs elevator" for handling 6-inch drive pipe is standard equipment. The elevator clamps around the pipe directly under the coupling, and is used for picking up pipe and for lowering and raising pipe in the hole. The sand line may be used with the elevator for lifting one or two half-lengths of pipe. For heavier strings of pipe, use the elevator with the swivel hook attached to the rope



1. Pin with swivel hook.
2. Elevators.
3. Pipe tongs.
4. Casing-ring slips.
5. Casing ring and slips.

Figure 75. Casing tools.

socket on the drilling line. Smaller elevators are furnished for handling the pipe column when setting the Peerless Hi-Lift pumps.

f. Hook, swivel-pin. The swivel-pin hook ((1), fig. 75) is attached to rope socket on the drilling line and used for lifting heavy strings of pipe with the elevators. It can also be used for picking up heavy pieces of equipment within working radius of the drilling line.

g. Casing ring and slips. The casing ring ((4), fig. 75) is used to

hold the casing at the well opening when raising and lowering long strings of pipe with the elevators. Two sets of slips are furnished, one set for 6-inch pipe and the other for 8-inch pipe. The casing ring is also used when pulling pipe from the hole by jacks placed under each side of the casing ring. Tremendous pressure can be applied by these jacks, so it is important that they be set on solid and even foundations and equal pressures maintained on both sides of the casing ring. The rings are cast steel, accurately machined, and fitted with handles. All slips ((4), fig. 75) are cast steel, with sharp steel teeth properly hardened, and are fitted with flexible cables for handles.

h. Pipe tongs. Two chain tongs ((3), fig. 75) are used for screwing up the 6- and 8-inch drive pipe. Should the pipe turn in the hole while the top length is being added, hold the lower pipe with one tong and

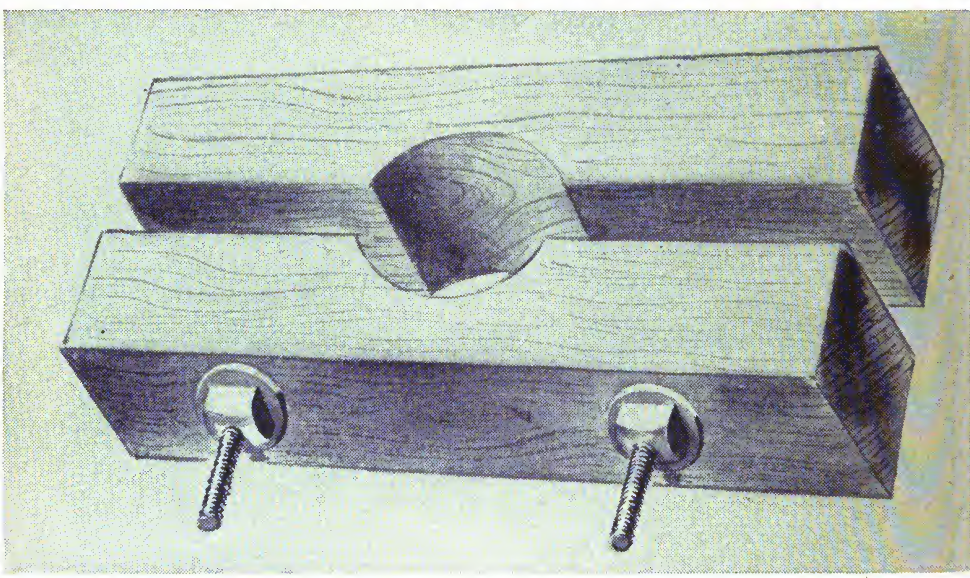


Figure 76. Wood pipe clamps.

tighten the top length with the other. If friction in the hole is sufficient to hold the pipe while making up top lengths use both tongs on the top length, one opposite the other. This puts an even strain on the pipe, easing the operation and making a better joint. It is imperative to make pipe joints tight and keep them tight while driving pipe, but without tong pressure enough to collapse the pipe.

i. Pipe clamps. Wood pipe clamps (fig. 76) are furnished for 6- and 8-inch pipe. They are used for holding the pipe at any desired position in the hole during drilling operations.

81. WELL SCREENS. Three types of well screens are used with the percussion drilling machines.

a. One type is wire-wrapped perforated pipe. These screens have 20- and 30-slot openings (0.020 and 0.030 inch, respectively) in both 5- and 10-foot lengths. Standard 4-inch pipe is used for the base, with the ends threaded and coupled. Lead packers and bail-plug bottoms are standard equipment for the screens when they are used in wells drilled with the percussion machine.

b. Some brass tube type screens or strainers are used. These are made from special, hard-drawn, seamless, brass tubing. The slots are cut from within the tube and are larger inside than outside. Any particle that is able to enter a slot will pass through without choking the opening. Standard fittings consist of a lead packer at the top and a bronze bail plug at the bottom. The screens are 10 feet long and 5 5/8 inches outside diameter.

c. The latest type of screens are the continuous-slot type, consisting of wire, wrapped vertical rods having sufficient strength to eliminate the need for a pipe base (fig. 56). The screens have 16- and 40-slot openings and are 10 feet long. They measure 5⅝ inches outside diameter. They have female screen coupling threads at both ends, and have fittings with male threads for making flush-joint connections between sections of screen. The following accessory equipment is furnished with these screens:

(1) Bottom shoe for bailing down the screen. The shoe has male threads to screw into the 5⅝-inch-outside diameter screen and has standard 4-inch female pipe threads at the lower end.

(2) A 4-inch, extra heavy pipe nipple, threaded on one end to screw into the lower end of the bottom shoe.

(3) A weighted wood plug to fit in the extra heavy 4-inch pipe nipple.

(4) A lead packer fitted on a 4-inch pipe coupling with right-hand threads on the lower end and left-hand threads on the upper end, for sealing 5⅝-inch-outside diameter screens inside 6-inch inside diameter pipe.

(5) A 4-inch pipe nipple with right-hand threads on one end and left-hand threads on the other.

(6) A bail plug with male threads, to screw into the bottom of the screen.

d. Surge block. The surge block (fig. 77) is used for surging the well during development. It is equipped with a 2- by 3- by 7-inch American Petroleum Institute pin joint and is used on the bottom of the drilling stem. The surge block draws the fine sand into the screen, allowing the coarser materials to accumulate around the screen, thus developing the greatest possible permeability in the material around the well. Do not use drilling jars with the surge block. The surge block is lowered into the water column and can be operated 20 feet below the high-water level,

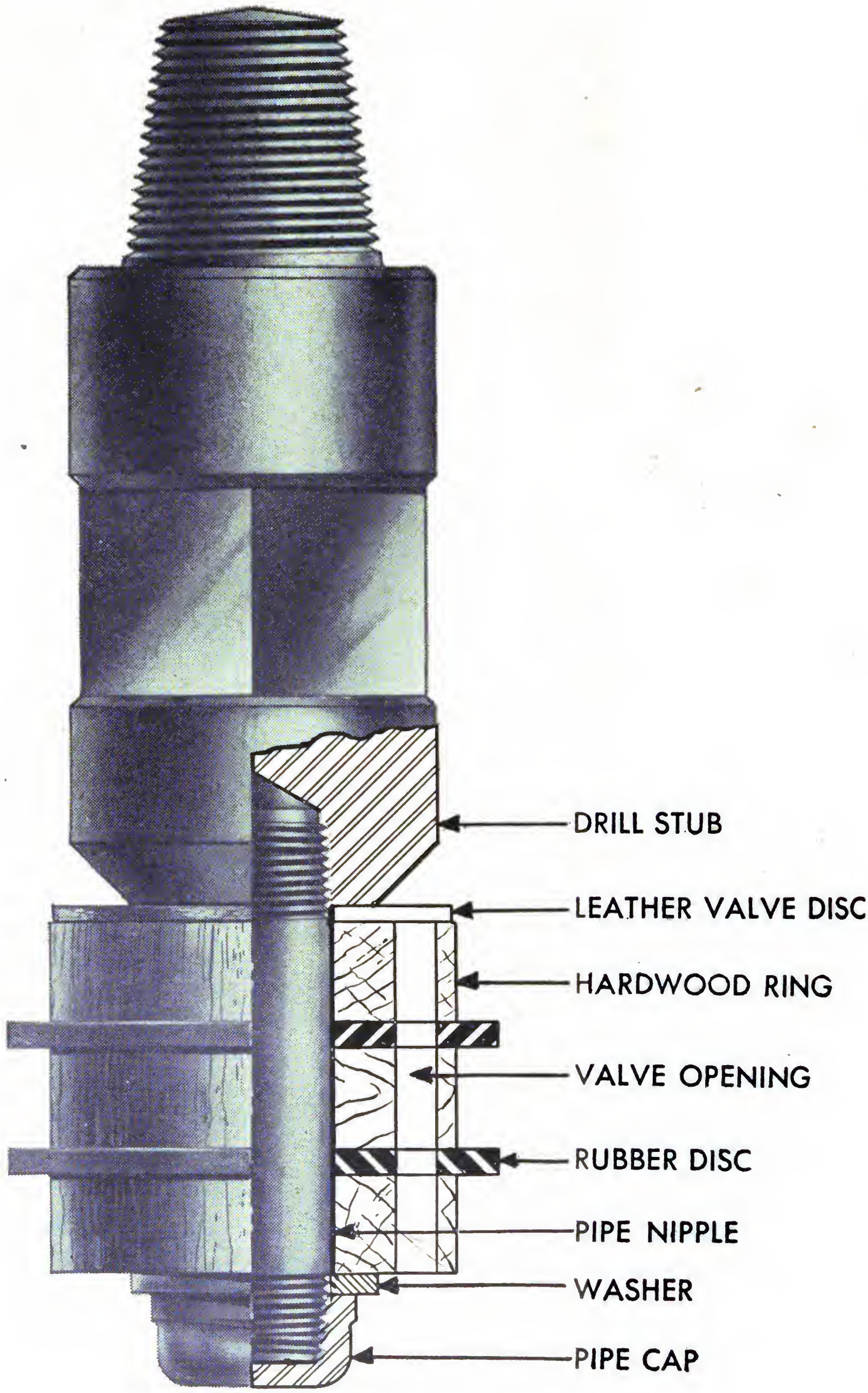
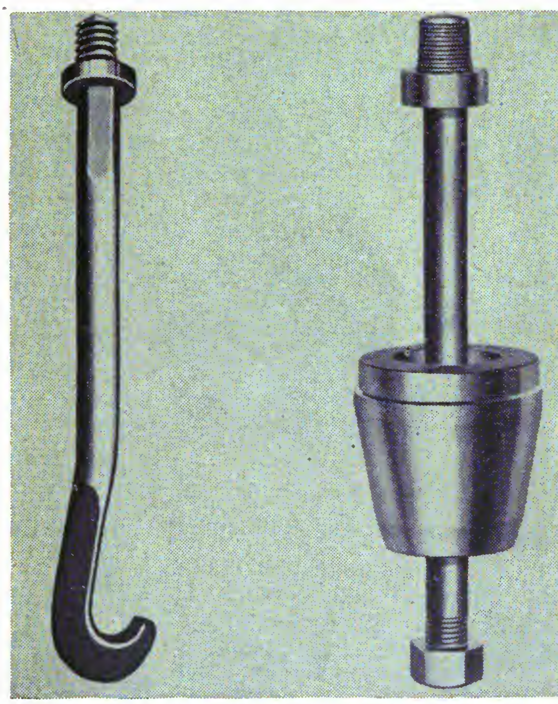


Figure 77. Surge block.

or a few feet above the screen. The screen must not be struck while surging. The surge block is run up and down by the drilling motion of the machine. Start by running slowly, gradually increasing the speed until the surge block will rise and fall without causing the drilling line to slacken. After surging for a short time pull out the surge block and with the sand pump remove the fine sand that has been drawn into the screen. Repeat the process until no more sand is drawn into the screen while surging. To avoid excessive wear on the surge-block washers, always operate the surging block between pipe joints.

e. Swage block. The swage block (fig. 78) is used to expand the lead packer at the top of the well screen to the inside wall of the well pipe, making a sandtight joint. The swage block is attached to the bottom of the rope-knife sinker jars and lowered into the lead packer. A few short, light taps, made by dropping the sinker bar on the swage block approximately 8 to 10 inches, will expand the lead packer. Do not lift the block out of the packer while swaging.



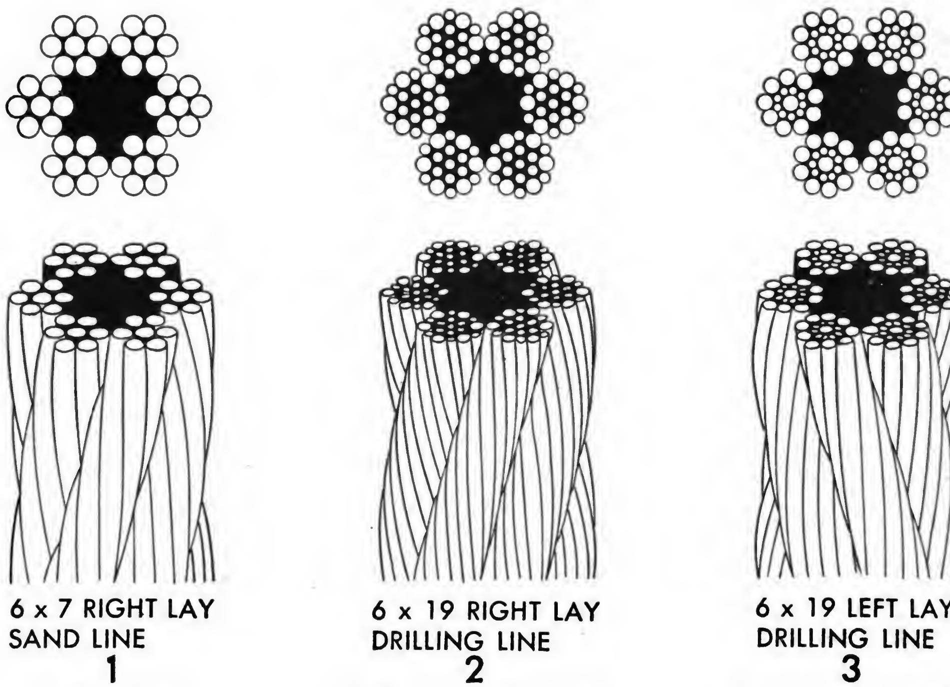
Ⓐ *Strainer hook.* Ⓑ *Swage block.*

Figure 78. Screen tools.

f. Strainer hook. The strainer hook (fig. 78) is used on the bottom of the rope-knife sinker jars for lowering the screen into the hole. It hooks into the bail on the inside bottom of screens equipped with a bail plug. The strainer hook is not used to pull a screen that has been set and swaged in a well. For directions on removing screens from wells refer to chapter 9.

82. WIRE ROPE.

a. Drilling lines. Drilling lines are "soft laid" lines. These are made up of 6 strands, 19 wires to the strand, and have a hemp core. The rope is either left or right lay. Left-lay cable is recommended for drilling, because the threads in the tool joints are right-hand and hence left-lay cable tends to tighten the joints. Left-lay cable is illustrated in (3), figure 79; (2), figure 79, shows right-lay line. The rope is made of cast steel or mild plow steel. For the strongest and most flexible rope mild plow steel is recommended. The drilling line handles the drilling tools and most fishing tools.



1. Sand line. *2. Right-lay drilling line.* *3. Left-lay drilling line.*

Figure 79. Wire rope.

b. Sand lines. Sand lines ((1), fig.79) are right lay, have six strands, seven wires to the strand, and a hemp core. Mild plow steel is used for sand lines. The sand line is used for all bailing operations, for some fishing work, for swabbing, and for other lightweight lifting purposes within the working radius of the line.

c. Unreeling and spooling. (1) When removing wire rope from the spool in which it is received, the spool must rotate as the rope unwinds. Attempts to unwind wire rope from stationary spools result in kinking it and a kink ruins the rope beyond repair at that point.

(2) To unwind the wire, mount the spool on a shaft supported by blocking either end, anchoring the shaft on the blocking so the spool

revolves on the shaft. Pull rope from the under side (machine side) of the spool up, over, and through the sheaves to the machine reel on which it is to be spooled. Anchor drilling and sand lines to the reels as described in TM 5–2002.

(3) When unreeling from spool to machine reels, keep the rope under tension and allow no slack, to obtain tight and even spooling on the machine reel. Use a plank pried against the side of the spool to act as a brake. It should take a decided pull to unreel the rope.

(4) The method described below for one-layer winding may be used to determine the proper direction of rope lay for spooling or winding on flat or smooth-face drums. When a rope is wound on to a drum, any tendency of the rope to twist when tension is released will be in a direction that would untwist the rope at the free end. The advantage in applying rope

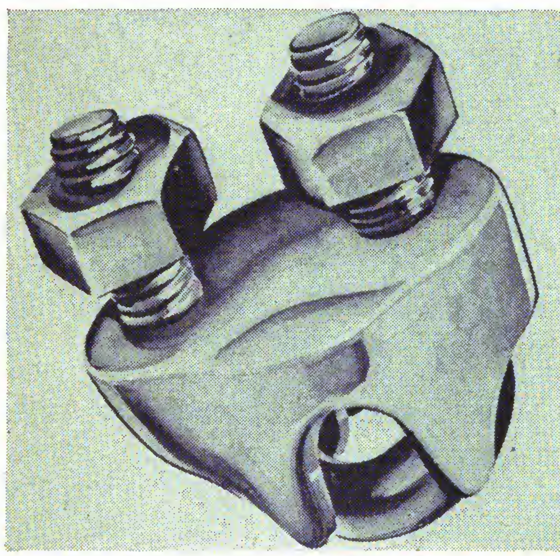


Figure 80. Crosby clip.

of proper direction of lay is that, when the load is slacked off, the several coils on the drum hug together and maintain an even layer. With rope of improper lay, the coils spread apart at each removal of load and, when winding is resumed, the rope may criss-cross and overlap on the drum, with resulting flattening and crushing of the rope.

d. Efficiency of wire rope attachments. Fastenings or attachments often are necessary in fastening pieces of wire rope together or to tools. The different attachments and methods of making connection may affect their efficiency. If we take the breaking strength of wire rope as 100 percent, a zinc socket, properly made will be as strong as the wire itself, or 100 percent; but if babbitt or lead is used, the efficiency may be as low as 25 percent, or one-fourth the strength of the wire rope. Wedge type sockets develop about 70 percent of the wire rope strength. In using clips of the Crosby type (fig. 80) the efficiency of the connection depends

on the arrangement, number of clips, and care used in tightening. With a properly made attachment, that is, with a clip basket on the load rope and a U-bolt on the loose end, the efficiency is 80 percent; with U-bolts all on load rope, 70 percent; with knot and clips, 50 percent; staggered clips, 75 percent; with improperly tightened clips, 50 percent or less. To make an attachment that develops approximately 80 percent of the strength of a 6- by 19-inch plow-steel rope, the number of clips shown in the table below are required. Ropes less than 3/4-inch should have not less than four clips.

Diameter of rope (inches)	Number of clips	Space between clips (inches)	Efficiency of fastening (percent)
3/4	5	4½	77.4
7/8	5	5¼	70.1
1	5	6	77.9

e. Setting wire line in swivel or Babcock socket. Wire cable can be attached to the swivel wire-line socket either by using zinc or babbitt metal, or by the "dry method." The dry method is used when it is impractical to use the zinc or babbitt method, is much more difficult, and as the strain may be placed on only a few strands of the cable, does not provide as satisfactory an attachment. The correct procedure for fastenng the cable in the socket is as follows:

(1) Zinc or babbitt method. First wrap the end of the cable with a binder of small wire or electrician's tape to prevent the cable from unlaying and to make it easier to insert in the swivel. Pull the cable through the socket and insert it in the top or cone-shaped end of the swivel. Push the cable through the swivel for 2 or 3 feet. Place another binder of wire about 5 inches from the end of the cable to prevent unlaying back of this point. Remove the end binder and unlay the strands back to the second binder. Cut off the core at this point and untwist each strand so the individual wires are separated. This operation is called "mule tailing." Pull the swivel back over the end of the cable until the ends of the wire are flush with the end of the swivel; then wrap a string or rag tightly around the cable at the point where it enters the swivel. Tie the swivel to a stake in a vertical position where it will be convenient for pouring the molten metal. Be careful in heating the metal, as overheating or burning results in a weak binding between the metal and the swivel. When the zinc is melted or the babbitt is heated sufficiently to "flash" a pine stick, pour it immediately into the swivel, filling it to the top.

(2) Dry method. When no babbitt metal is available an almost equally satisfactory method of fastening the wire in the swivel is as follows:

insert the cable through the socket and swivel as described above. Wrap the cable with a wire binder about 6 inches from the end to prevent the cable from unlaying past this point. Take a piece of *soft wire* or *cotton string* and wrap it tightly around the binder, building it up to a diameter of 1½ inches and a length of 3 inches, tapering in each direction from the center to the ends. Next, unlay the strands and bend them back over the knot of soft wire or string, and cut off the core. Then pull the ends of the strands against the cable and insert them in the swivel; use a hammer to drive the knot into the swivel. This method, if properly used, will be satisfactory in all shallow water well drilling.

f. Proper working loads for wire rope. (1) The working load of a wire rope for general purposes, particularly running ropes, should not exceed one-fifth of the breaking strength; that is, the factor of safety should be not less than 5. To find the proper working load, divide the breaking strength by the proper factor of safety. A ⅞-inch diameter, 6- by 19-inch plow-steel rope has a breaking strength of 28 tons; with a factor or safety of 5, the proper working load would be not over 5.6 tons.

(2) Factors of safety in excess of 5, up to 8, and even more, often are required for safe and economical operation. The proper factor of safety for a wire rope is determined by careful and thorough consideration of all pertinent data. Such data include all loads; acceleration; deceleration; rope speed; rope attachments; the number, size, and arrangement of all sheaves and drums; existing conditions causing corrosion and abrasion; length of rope in service; economical rope life; and the degree of danger to life and property.

(3) No arbitrary values for factor of safety can be properly set for various classifications of service. They can safely vary, within limits, with the conditions met in individual installations. Safety factors of 5 and 3 have been used in handling drill pipe and in setting casing, respectively. Low safety factors invariably lead to erratic results.

TABLE II. *Safe working load of new 6- by 19-inch wire rope*

Diameter (inches)	Weight (pounds per foot)	Safe working load (tons)			Smallest sheave diameter (inches)		Factor of safety
		Iron	Crucible steel	Plow steel	Iron	Steel	
⅜	0.22	0.48	0.96	1.02	27	18	5
½	.39	.78	1.68	1.75	36	24	5
¾	.89	1.70	3.50	4.00	54	36	5
1	1.58	2.90	6.00	6.00	72	48	5
1¼	2.45	4.60	9.40	10.40	90	60	5
1½	3.55	6.60	12.80	14.80	108	72	5
2	6.30	11.00	21.20	28.00	144	96	5

g. Lubrication of wire rope. In order to obtain maximum service from wire rope, frequent application of some kind of lubricant is necessary so the hemp core may not become dry. A dry core wears and crushes more quickly, and absorbs moisture, to the serious detriment of rope service. A good lubricant retards corrosion of the wires and reduces internal friction and external wear. Any one of a number of special wire rope lubricants will give excellent results if properly applied at specified intervals. Any kind of lubricating oil is better than none. The smaller the sheaves, or the heavier the load, the more often the rope is lubricated It is better to lubricate wire rope too often than not often enough.

SECTION IV
OPERATION

83. CREW. The number of men required to operate a percussion drill efficiently depends on the experience and ability of the drilling crew, and to a certain extent upon the type and size of the equipment employed. For the No. 71 Speed Star, when permanently truck-mounted, two experienced men usually are sufficient. For the efficient installation of the Star 71SK skid-mounted unit, which must be unloaded and mounted on cribbing (figs. 59 and 81), at least four men are needed for unloading and installation. In either case an additional man is required as truck driver for hauling water and supplies to the drill.

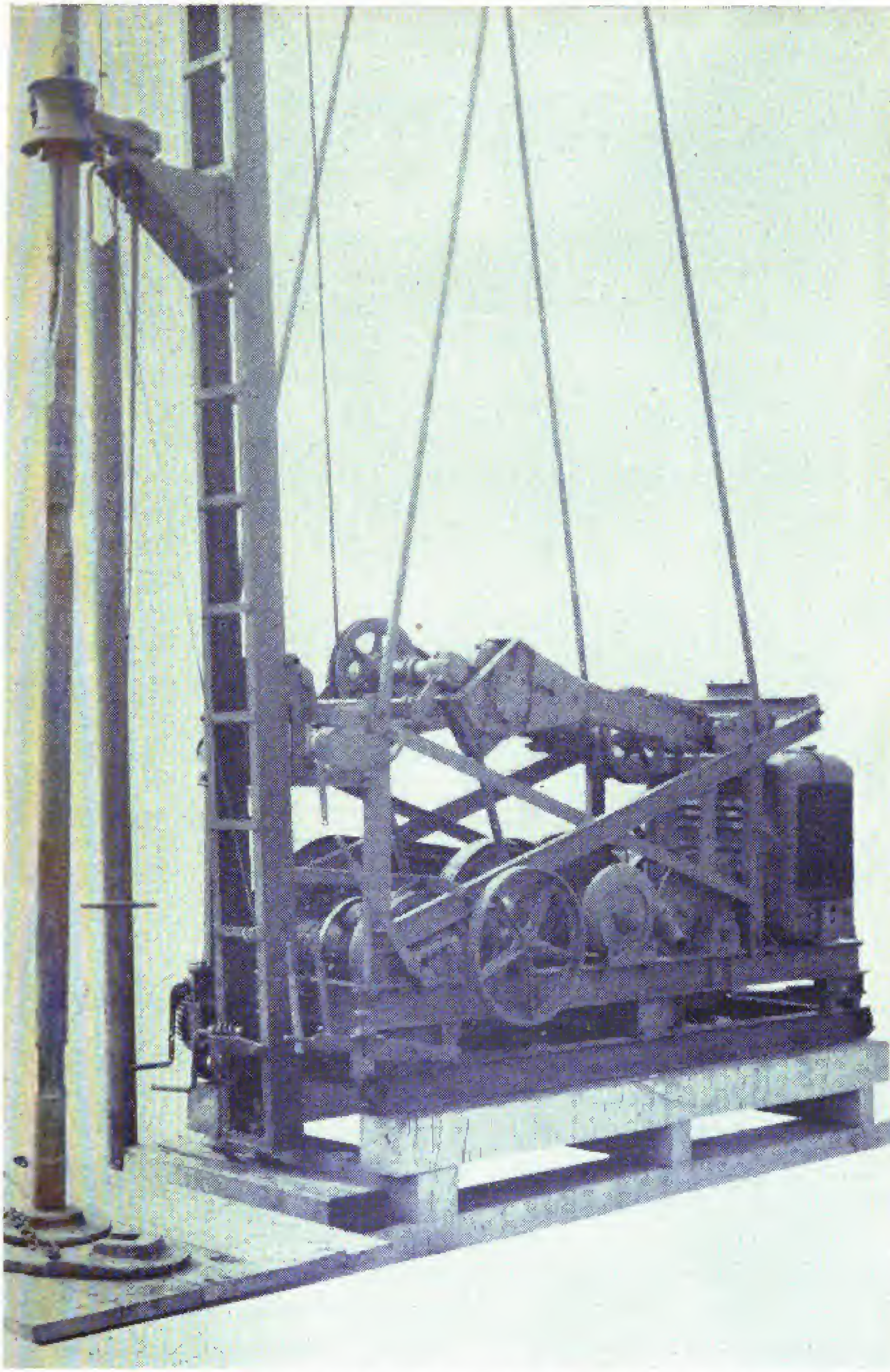


Figure 81. Close view of the No. 71SK Star percussion drill, on cribbing in operation position.

84. WELL LOG AND SAMPLING. The well log is a written record of the geologic formations met as the well is drilled. It also includes a record of the pipe in the hole, and any other pertinent information that will expedite the successful completion of the well. In percussion drilling, an accurate measuring string should be carried on the bailing line at all times. This is especially useful when drilling in soft, unconsolidated formations where it is necessary to drive the pipe as drilling progresses. If the exact length of the pipe in the hole is not known, as well as the depth at which water-bearing formations are met, the pipe may be driven through the water-bearing formation, shutting it off completely. The action of the percussion drill cannot be depended on for information regarding the types of formation being drilled, except that a definite change in the rate of penetration usually denotes a change of formation. The color of mud or samples is used in logging the well, principally to differentiate between beds of the same kind of material. Samples are taken with each change of formation, and additional samples made every 5 feet. These samples are caught by dumping the first bailer load in a bucket. The sample often is necessary for locating suitable beds in which to seat casing, for delimiting water-bearing beds, and for learning other vital information regarding the well. Samples are saved by placing them in canvas bags or on boards, as shown in figure 53.

85. WATER SUPPLY. A water supply is necessary for drilling wells with the percussion drilling machine. Crevices or a dry sand may absorb water from the hole, making it necessary to add water sometimes in large volumes, as the hole is drilled. When sufficient water for drilling is found at a shallow depth, no additional water is needed. Under average conditions, 4 gallons of water are required for 1 foot of 6-inch hole, and 5 gallons for 1 foot of 8-inch hole.

86. SETTING UP DRILL. In setting up the 71SK drilling machine, first place the crib mount in the desired place. Make sure the cribbing is level, and has sufficient mud sills, properly distributed, to prevent settling or misalignment of the drill after drilling has started. Four 2- by 12-inch timbers, 5 feet long, will suffice unless the well is drilled in a swampy or poorly drained location. In such case, additional mud sills are installed. Figure 61 shows the cribbing in place and the 71SK machine being skidded from a trailer onto the cribbing. Figure 81 shows the drilling machine in place with the mast erected ready for drilling. After the mast is raised (see TM 5–2002) the drilling tools to be used for spudding-in are assembled. They are swivel socket and swivel, drill stem, and drill bit.

87. SPUDDING-IN. a. Spudding-in with percussion tools is similar to ordinary drilling procedure except that the tools work above the surface. For this reason the movements of the tools are controlled to prevent injury to the drilling crew or damage to the drill.

b. After securing the cable in the socket, clean the threads on the drill stem and bit of all grease and dirt. Then apply a little light machine oil to the threads and shoulders of the pins. This prevents rolling and chafing of the threads and shoulders of the joints when they are unscrewed. After the rope socket and bit have been screwed on the drill stem by hand, tighten them with chain tongs, or with the tool wrenches and chain bar. When the tools have been tightened, place the wire-line saver on the end of the swivel socket before raising the tools up the mast. This prevents a kink or "dog-leg" in the cable, which would soon result in a broken or stranded cable in the hole. When the tools are swung on the mast, see that they hang directly down the center. Then set the tools down on the ground hard enough to mark the spot where the hole will be drilled.

c. In starting a hole in soft, unconsolidated formations, dig a hole about 3 feet deep with a shovel. Let the tools down until the bit rests on the bottom, then fill the hole with water around the bit. Start the tools by throwing in the spudder-beam clutch; run them slowly, and guide their movement by hand until a depth of 6 or 8 feet is reached. If a tool guide is not available for use in steadying the top of the tools, station a man in the mast for that purpose. In starting the hole in hard rock, dig or chisel out a hole 6 inches deep at the spot where the drill is to work. Set in a hole a 5- or 6-foot length of pipe, of the same size as the hole to be drilled. Then brace and chain the top of the pipe to the mast, as a guide for the tools; if it is securely installed, the tools can be run at a comparatively high drilling speed.

88. DRILLING.

a. Procedure. (1) Drilling operations naturally differ with the character of formation and depth of hole. For those differences, the 71SK machine has two types of adjustment in the spudding mechanism. One is the multiple holes in the crank arms, and the other is the spring tension adjustment on the spudder shock-absorber springs. These adjustments are explained in TM 5–2002.

(2) Proper adjustment of the spudder assembly eliminates line whip, drill shock, and vibration, and increases the efficiency of the machine. Tension on the springs must not cause the spudder shaft to return to normal position with a quick snap, as this causes a decided whip in the line, line wear, and excessive shock, and in most cases will spoil the drilling motion.

(3) Operating speeds differ with depth and character of the hole. Run the drill only fast enough to permit smooth operation and to let the tools drop with a clean, hard blow. Use a tight line in creviced and irregular formations. In hard rock and abrasive formations, keep the drill bit to gauge. Do not allow it to wear to a point at which the next full-gauge bit will stick, necessitating reaming of the hole before it will work freely. Reaming causes undue wear on line, jars, joints and machine, and loss of time. If drilling progress is not satisfactory, yet the hole is straight and tools are working freely, change to either a longer or shorter stroke, depending on the formation. A 32-inch stroke, however, with approximately 1,700 pounds of tools, produces the best results in almost nine-tenths of all hard-rock drilling. As a guide consult the following table:

57 to 65 strokes per minute, 18-inch stroke.
50 to 57 strokes per minute, 22-inch stroke.
43 to 50 strokes per minute, 32-inch stroke.
35 to 43 strokes per minute, 40-inch stroke.

b. Wet and dry drilling. **(1)** A "wet" hole is one in which there is more water than is required for drilling. A "dry" hole is one in which excess water is cased off or is absent during the sinking of the well. In oil fields, these terms are applied in a different sense, a wet hole being a well that yields oil and a dry hole one that does not.

(2) Drilling is faster in a dry hole, as the tools are not buoyed up by water; the rope lasts longer because it is not saturated; and the tools, if lost in the hole, can be recovered more easily, as fishing tools are used to better advantage in a dry than a wet hole.

c. Drilling hard rock. **(1)** In drilling hard rock it is good practice to carry the jars in the drilling string at all times. They are of no benefit in actual drilling, but their usefulness in the drilling string arises from the nature of hard rock drilling in which caving formations, crevices, or other conditions may cause the tool to stick at any time and make the use of the jars necessary. When used to loosen tools that are stuck in the hole, enough slack is let out on the drilling line to cause the jar links to hit a sharp upward blow with each stroke of the spudder beams. If the hole does not contain sufficient water for drilling purposes, enough is added to keep the jars covered at all times, to prevent excessive wear. The principal difficulties encountered in drilling hard rock are caving formations and crooked holes.

(2) Formation caving is a common cause of trouble in hard rock drilling. Pieces of rock roll in the hole, wedging the tools tightly against the wall. Occasionally these caves make further progress impossible. In this case the hole is filled up to the top of the cave with cement and left for 24 hours, when the cement can be drilled out and drilling resumed.

The only alternative to this method is to run a string of casing. In less extreme cases the cave usually ceases to cause trouble after the tools have passed through it.

(3) Crooked holes usually are due to dipping or shattered formations, crevices, or subterranean caverns. Usually the first indication that the hole is leading off is that the drilling tools begin to stick. After being jarred loose they run a few strokes and stick again. This erratic operation is caused by the tools turning in the hole until the drill stem binds against the wall when the tools strike the downward blow. When this happens, drilling is stopped and the hole brought back to vertical. Usually this is done by filling the hole with pieces of cast iron to a level slightly above the point where it started to deviate from the vertical, and drilling the iron out with the tools. If cast iron is not available, fill the hole with rock for about 2 feet, then drop in a piece or two of wire drilling line, 6 inches long, which has been heated to red heat to remove the temper. Continue in this manner until the hole has been filled to a point about 2 feet above where it started off the vertical. It will usually be found necessary to fill up and drill out the hole several times before it is straightened sufficiently to resume drilling.

(4) The most efficient use of the swivel socket in drilling rock usually is attained by running with a slightly loose line. The line should not be loose enough to allow flexing or working of the jar links, but the tools should hit a solid, positive blow on the bottom, with considerable swivel action on each stroke.

(5) Bits are dressed at intervals frequent enough to prevent excessive sticking when a new bit is run to the bottom. For best results, different types of formation require slight differences in the shape of the bits, but in ordinary hard-rock drilling a bit dressed to slope about 30° from the cutting edge is satisfactory. Occasionally slate and shale will be encountered that cannot be drilled successfully until the wearing surface on the bit is reduced to the minimum. Keep the bit corners dressed out to gauge, as they exert a reaming action which is beneficial when drilling through broken or creviced formations.

d. Drilling unconsolidated formations. Drilling unconsolidated formations is principally a mixing job. The drilling bits are dressed with a short bevel, and the wrist pins of the drilling machine are adjusted to give a long stroke to the tools. Light-weight tools run at a moderate speed give good results. Penetration must not be too rapid, or mixing will be incomplete. A formation of high textural range containing sand, gravel, and clay generally drills better than a more homogeneous material. A few shovelfuls of clay added to the hole facilitate drilling in loose sand. Small amounts of sand or sandstone are added to the hole when drilling in clay is being done.

89. BAILING.

a. The cuttings are bailed out as the hole is drilled. Four to six feet of hole generally can be made at each "run" of the tools. However, conditions differ greatly, and no rule can be set. A clean hole drills better than one filled with thick mud, but in soft formations the mud tends to prevent the hole from caving. Therefore, sometimes it is better not to bail out all mud and water but only the thicker, heavier part at the bottom of the hole. In this way the hole is kept in better drilling condition than if bailed out clean.

b. When drilling a consolidated formation the bailing operation is quite regular. After each "run" the tools are pulled from the hole and swung aside while the bailer is used. If the bailer goes to the bottom and the hole is in good condition, the pick-up will be indicated by two jerks on the sand line. The jerks will appear about 1 second apart and are the result of the pick-up of the bailer and the pick-up of the bailer dart valve plus the fluid within the bailer. After lifting the bailer 4 or 5 feet it is lowered and raised once or twice more, as this tends to draw into the bailer any sand or material that might have settled on the bottom of the hole. If the double jerk referred to above is repeated each time the bailer is lifted, it is safe to assume that the hole is in good condition.

c. If only one jerk is noticed as the bailer is lifted, it indicates the bailer did not reach the bottom of the hole, and the trouble is corrected before attempting to drill deeper. The trouble may be caused by the failure of the bit to turn, and the flatness of the hole; or, the hole may be so crooked that the bailer will not reach the bottom. Other causes could exist, such as a ball of mud or a boulder projecting into the hole. Remedies for such troubles are given in paragraph 99.

d. A sand pump gives a signal on the line in the same way as the bailer, except that the jerks are much farther apart. If the pump is allowed to rest on the bottom of the hole, and the plunger is lowered to the bottom of the tube, the first jerk will indicate the pick-up of the plunger, and the second pick-up will be that of the tube. The two signals will be some seconds apart, owing to the length of the plunger. Flag the sand line, and keep a careful check on the progress of the bailer as compared to the depth of the hole. When there is a good depth of water in the hole, lower the bailer carefully, so it does not strike the water with too much speed and allow the line to slacken, as this may result in a broken line if the sand reel is stopped while the bailer is plunging downward. Also, loops of slack line may injure persons standing near the hole.

e. A bailer link is convenient in making frequent changes from bailer to sand pump or bumper. Ordinarily the sand line is tied to the top of the bailer link. Sometimes a wire line clamp is used, but this makes recovery

of the bailer more difficult in case of a fishing job caused by the sand line breaking a short distance above the bailer. The broken end of the line, with clamp, may wedge between the wall of the hole and the bailer tube, causing the bailer to stick in the hole.

90. DRIVING PIPE. Pipe is driven with the drilling tools, the drive clamps, and usually the drive head.

a. Procedure. (1) A joint of drive pipe is set up and screwed into the casing string. The drilling tools then are lowered down into the pipe far enough so the upper square on the drill stem is just above the top of the pipe to be driven. The drive clamps then are bolted on the square of the drill stem.

(2) Tighten securely the bolts that hold the clamps. With the machine, pick up the tools far enough for the clamps to hang about 5 inches above the drive head, which has been placed directly on the drive pipe. This space between the clamps and drive head puts a high tension on the shock-absorber springs with each stroke of the tools, and gives the tools a quick, positive pick-up. After picking up the tools, throw in the spudding-beam clutch and drive the pipe down, running the tools at ordinary drilling speed. After driving for a few feet the driving speed often will slow down or stop altogether. As the diameter of the hole is less than the outside diameter of the casing shoe, driving or forcing the shoe down through this smaller hole often plugs the pipe. When driving progress is delayed for this reason, the tools are run to the bottom and the hole cleaned out. The bit is carried on the drill stem at all times while the pipe is being driven. The additional weight of the bit is important, because the standard 4¼-inch by 16-foot drill stem is not heavy enough for efficient pipe driving.

(3) Do not drill farther ahead of the drive shoe than is necessary to drive in one joint of pipe at a time, and never, under any circumstances, drill ahead far enough to place the rope socket below the shoe joint. When a new joint is set up for driving it will usually be found that driving progress is slowed up considerably as the drive shoe approaches the bottom of the hole. Cleaning out sometimes is necessary before the pipe has been driven far enough to allow the tools to be removed from the pipe for running the bailer. In this case the tools are worked down into the cavings as far as possible, and then pulled back to the top of the pipe and driving resumed. If this method of alternate driving and drilling is followed the pipe usually can be driven to a point where the tools can be removed from the pipe for running the bailer.

(4) It is important that the first 40 or 60 feet of pipe go straight. A plumb bob, or a level used on two sides of the pipe, will enable the driller to determine whether this is the case.

(5) Some formations of sand and gravel heave up into the hole and fill the pipe with sand which, after settling, reacts to the bit more solidly than in its original state. Heaving that occurs while the drilling tools or bailer are at the bottom of the hole is indicated by a slackening of the line, and should be followed by *immediate* withdrawal of the tool in use, as some sands will settle in a few seconds.

(6) Heaving sand can be controlled by adding clay and water to maintain a hole full, or partly full, of fluid mud. When driving is extremely difficult, it is not always advisable to prevent heaving completely. A pipe which is driving hard will drive more readily following a heave. Heaving, encouraged by bailing and followed immediately by driving, results in better progress, although where boulders may be encountered there is some risk with this method. The distance of the drive that can be made generally is between 1 and 4 feet. Heaving sometimes occurs before the hole is cleaned out.

(7) Some formations of soft clay do not "stand up" to allow a hole to be made ahead of the pipe. Such formations generally can be handled best by driving the pipe ahead of the bit and cleaning out to the bottom of the pipe after each drive. However, when driving pipe ahead of the bit, the pipe may come in contact with a large boulder, or perhaps reach bedrock, while driving is in progress. It is important to make some hole ahead of the pipe, if possible, as the bit might break up or dispose of the boulder. If the tools pass alongside the boulder without knocking it out of the way the hole can be filled up above the boulder with any other available rock. In redrilling the hole the offending boulder may be broken up and the way cleared for the pipe. A few sticks of dynamite can be used with good results on boulders, providing the pipe can be withdrawn at least several feet from the explosion, to prevent damage.

(8) By drilling, and considerable bailing around and below a boulder, using clear water without clay, the material surrounding the boulder sometimes can be undermined and the boulder drawn within reach of the drilling bit. Dressing bits full to the bit gauge, and with a sharp reaming edge, is important when drilling in a boulder-strewn formation.

(9) In a well in which the hole is drilled into bedrock ahead of the driven pipe, and it is desired to drive the pipe on to the bedrock, care must be used to prevent the drive shoe being pinched in. The bit drills a cone-shaped hole as it enters the rock, and the shoe will collapse more readily when forced into such a hole than when striking against a flat surface of undrilled rock.

(10) In localities requiring 400 feet or more of drive pipe it may be found necessary to start a second string of pipe. Sometimes, when driving, the second string of pipe compresses and recoils with the blow

of the tools, making it impossible to drive. This condition may arise when there is little wall friction on the inside string of pipe. A remedy sometimes is to fill the annular space between the two strings of pipe with heavy, fluid mud, free from sand or gravel.

b. Use of jars. The jars are never used while driving pipe, for the following reasons:

(1) If properly dressed bits are used in the soft, unconsolidated formations in which pipe is driven, the tools seldom stick.

(2) Using jars in hard pipe driving slows down the operation as much as 25 percent.

(3) When the jars are installed in the drilling string, fuel consumption increases as much as 10 percent.

(4) If good drilling practice is followed, and the top of the drilling tools are kept in the drive pipe on the rare occasions when they do become stuck it will be easy to knock them loose with the jar bumper or to cut the line and fish them out.

c. Seating drive pipe. **(1)** Seating drive pipe properly is important. Where the hole is drilled below the pipe into consolidated formations, the pipe is bedded on or into the hard material. If it is not, probably the material above the rock eventually will seep into the rock hole. This, in turn, would fill up the hole and at the same time, especially in shallow wells, allow surface water to enter the well and possibly contaminate it. If an 8-inch hole is started and carried to the rock, and a 6-inch hole is to be drilled from that point on, drill the 8-inch hole into the rock from 5 to 20 feet, then set in the 6-inch pipe. Then cement the space between the 8-inch hole in the rock and the 6-inch pipe, thus making a waterproof joint.

(2) Where it is not feasible to seat the well pipe as above, a seat is made on top of the rock. Before setting the pipe on rock, let the tool string start the rock hole slowly. The drill will start a cone-shaped hole somewhat larger than the pipe, and gradually taper down to bit gauge. Drive the pipe into this cone-shaped pocket, and tap it lightly. A sandtight joint between pipe and rock hole can be made in this manner, but not a watertight joint. If conditions are favorable, a wet cement mixture can be packed around the outside of the pipe and the top of the rock by forcing it down and under the pipe with a plug and the tool string.

91. FORMATION RECOGNITION. During cable-tool drilling formation recognition is limited to the hardness of the formation being drilled. Factors to be noticed while drilling hard and soft formations are as follows: hard rock drilling imparts distinct vibration to the drilling cable and requires slightly less power to operate the machine at a given speed. Therefore, if the drilling tools reach a noticeably harder formation after

in any certain operation. The estimates of average drilling speed given below are based on a 6-inch hole, 350 feet deep, and an 8-hour day, under ordinary drilling conditions:

	Feet
Quicksand	30
Gravel	30
Shale, sticky	20
Shale, sandy	50
Clay, sticky	30
Clay, sandy	70
Boulders	15
Sandstone, hard	20
Sandstone, soft	75
Conglomerate	20
Slate	80
Limestone	40
Dolomite	15
Granite	12
Metamorphic rocks	25
Lava	12

94. CASING IN WATER WELLS.

a. Use. Casing is used in drilled water wells because water has a harmful effect on the walls of holes that penetrate unconsolidated formations such as soft shale, clay, sand, and gravel. When water wells are drilled in hard rock, casing seldom is necessary except when the rocks are overlaid by soft, unconsolidated material through which casing must be driven and seated, to prevent caving and sloughing of the unconsolidated material which would soon fill up the hole. In rock, only a short length of casing need be used at the surface, to prevent contamination. In Army work it will probably be necessary to case most holes.

b. Selecting proper size casing. **(1)** Selection of casing depends entirely on what is known regarding the formation in which the well is to be drilled. If the geologic features of the formation are unknown the largest casing available is used because of uncertainties in driving pipe, which are, principally—

(a) Possibility of striking thin beds of hard limestone, through which the pipe cannot be driven.

(b) Wide differences in frictional resistance to the drive pipe in different types of unconsolidated materials, which make it difficult to predict the depth to which any single string of pipe can be driven.

(2) Unsaturated sand and gravel often can be penetrated to considerable depths without casing, by dumping the drilling water on the bottom with the bailer. The procedure is to lower a bailer of water to the bottom of the hole and dump it by a chain or board fastened on the dart valve.

This method prevents caving or sloughing by keeping the walls of the hole free from contact with water except in a comparatively small area adjacent to the drilling tools. This method has the great advantage that the hole can be drilled first and the casing lowered afterwards, saving time ordinarily consumed in driving pipe.

(3) Either of the possibilities mentioned above may necessitate a reduction in hole size at any time. For this reason, where subsurface conditions are unknown, the hole is started at least one size larger than that necessary for completion.

c. Seating the casing. Seating the casing in water wells usually consists of driving the well casing into the hard rock for a few inches or several feet. The casing shoe is driven far enough into the rock to make a perfect seat, shutting out all surface water, silt, and sand that might enter the well. Often it is necessary to drive the pipe ahead of the tools until the rock is struck. When this is done, often it will be found impossible to seat the pipe properly until the tools have passed below the pipe, owing to the vibration in the pipe caused by the drilling tools. The drilling jars are especially objectionable in this respect. When the hole has reached a depth sufficient to place the tools entirely outside the pipe, the drive clamps are used to seat the pipe a few inches deeper in the rock. This accomplishes the desired result in most cases.

95. CEMENTING CASING. Cementing the casing in water wells usually is done by one of two methods.

a. Cement is pumped into place with mud pump. When the mud pump is used, the pipe is raised a few feet above the bottom and circulation is established with the pump, using a mud mixture of Aquagel or native clay. After circulation has been established, mix the cement with water (do not mix sand with the cement) so it is thin enough for the pump to handle readily. As soon as the cement is thoroughly mixed, pump it in the casing and follow it immediately with enough water to displace the cement in the pipe. The amount of water pumped in is calculated so that 10 or 15 feet of cement is allowed to remain in the bottom of the casing. After pumping in the water, the casing is lowered to the desired position and the valve on the casing head closed. This prevents the heavier cement mixture that has been pumped up around the outside of the casing from displacing the water in the casing. The valve is kept closed until the cement hardens.

b. Cement is dumped on bottom with bailer. When the casing is to be cemented by dumping the cement with a bailer, raise it a few feet off the bottom. Mix the cement thin enough so it can be poured readily from a bucket. After mixing thoroughly, fill the bailer with the mixture and lower it to the bottom with the sand reel. Fit the bailer with a chain

or some other device so the cement will be dumped when the bailer strikes the bottom. After dumping the required amount of cement, work the casing up and down the hole, causing some of the cement to move up on the outside of the casing. After working the casing up and down a few times, set it on the bottom and allow the cement to harden. After the cement hardens, the part of it remaining in the casing can be drilled out and the results tested.

96. CUTTING PIPE IN HOLE. A casing cutter may be used at any depth to cut pipe in the hole. The cutter is lowered on tubing, and the jars and mandrel are run on the same line and lowered inside the tubing. When the cutter is lowered to where the casing is to be cut the mandrel is run in and, by jarring downward, the cutters are forced out against the wall of the pipe. At the same time the tubing is revolved by tongs or by some other method. A complete outfit consists of cutter, mandrel, jars, sinker, and rope socket. A casing cutter is not regular equipment with the 71 Star machine.

97. SHOOTING WELL PIPE. To shoot off a portion of the well pipe in order to recover a part of it, dynamite is lowered to the point where the pipe is to be severed. Usually, for 6-inch pipe, three to five sticks of dynamite is sufficient to make a break. Set the dynamite as near a joint as possible. ***Caution:*** When shooting dynamite, do not cover the hole. Make personnel stand clear. After hearing and feeling the shot, wait a few minutes for the probable discharge of water and mud from the well opening.

98. RECOVERING PIPE. To recover pipe from abandoned wells, or the outer string of pipe from wells that have two strings of pipe, the casing ring with slips and jacks is used.

99. DRILLING DIFFICULTIES.

a. Causes of crooked holes. Crooked holes almost always are caused by peculiarities of the formation which the drill is penetrating and not, as often supposed, by the carelessness or inefficiency of the operator. This is especially true in formations such as those listed below:

(1) Metamorphosed rocks that are folded and cut by joints, faults, and cleavage planes.

(2) Boulder beds.

(3) Limestones with subterranean caverns, crevices, and mud-filled seams.

(4) Inclined rock formations underlying unconsolidated surface deposits.

b. Prevention of crooked holes. In only one of the types of forma-

tions listed above are preventive measures generally successful, namely when inclined rocks underlying surface beds of unconsolidated material are encountered. The best procedure under these conditions is to keep the casing as near the bottom of the hole as possible. If practicable, drive it ahead of the hole, making contact with the rock ahead of the bit. This method frequently will prevent trouble and delay when setting the surface casing.

c. Detection. (1) As indicated previously, the first warning that the hole is becoming crooked generally is received when the drilling tools begin to stick on the bottom. After the tools are jarred loose, they will run a few strokes and then stick again. This erratic behavior is caused by the wearing surface of the bit coming in contact with the side of the hole that is leading toward the center as the tools turn in the hole. This causes the top of the tools to rub and bind against the walls.

(2) When the tools are pulled out of the hole, after running a few minutes under these conditions, it will always be found that the bit is "dubbed off" at about a 45° angle around the lower edge of the wearing surface. Percussion drilling tools depend entirely on gravity for the speed and efficiency of their operation, and any deviation of the hole from the vertical that causes them to bind against the walls can be detected almost instantly by an experienced operator. This is more pronounced in the smaller sized holes such as 4-inch, 6-inch, and 8-inch, as the diameters of the tools and the hole are so nearly equal that even a slight deviation from the vertical causes the tools to bind.

(3) In larger diameter holes considerable deflections from the vertical occur without noticeable effect on the drilling motion, because from 10 inches up, the diameters of percussion drilling stems and jars do not increase in the same proportion as the hole diameters. The effect of this is to give the tools considerably more working space in the larger holes. However, the progress of even the largest holes can be followed by observing closely the wearing surface on the bit each time it is removed from the hole.

d. Stuck pipe. Sediment such as sand or limestone cuttings settling around the pipe is the usual cause of sticking. There is no foolproof method for preventing the pipe from sticking; however, a certain degree of relief is obtained by lubricating the pipe with mud. Jarring in the bottom of the pipe with a casing spear while pulling on the pipe with jacks ordinarily will pull the pipe. If the pipe starts and then becomes fast again, sometimes it can be loosened by driving it back to its original starting point and beginning again. If it is impossible to pull the pipe, the stuck portion may be shot or cut off with a casing cutter. If the

pipe becomes stuck and cannot be pulled within a short time, generally it is advisable to leave the hole and start a new one.

e. Damaged drive shoe. A drive shoe damaged by hard driving, or forced out of shape by a boulder, sometimes may be rounded out sufficiently to clear a smaller pipe. A drilling bit, of about the same size as the pipe, dressed with a feather edge and with the water-channels almost completely filled in, is a suitable tool to use. Placing the drilling jars between the bit and the stem prevents the bit from sticking while drilling out the shoe. Some benefit may be gained by filling the lower part of the pipe with fragments of hard rock, and drilling them out. Drill with a short or medium-length stroke.

f. Geologic difficulties. (1) Chips, fragments. Fragments of rock or loose stones may fall from the wall of the hole on top of the drill and wedge it so tightly it cannot be withdrawn by cable pull alone. This is a common accident in wells without casing or drive pipe, in highly creviced or fissured rock, or in glacial till. The fragments or loose stones usually can be broken up by a smaller drill and the tools then withdrawn. In brittle sandstone and in shale the top of the string of tools may become jammed in a cavity in the wall of the well, made by the detachment of rock fragments. Then the spudding spear is used to bring the string of tools into their normal position in the drill hole. They seldom can be loosened simply by playing on the cable.

(2) Boulders. Ordinarily the driller determines whether hard rock which the drill has struck is or is not a boulder by noticing whether it seems loose, and rebounds under the stroke of the drill. If it does not seem to be solid rock he endeavors to break it to pieces and remove it. The boulder may be so large that the driller mistakes it for bedrock, and after drilling into it for 3 or 4 feet sets the casing in the boulder, substitutes a smaller drill, and proceeds as if he were in bedrock, but after drilling a few feet farther he again encounters sand or clay of the same character as that above the boulder. He then must draw the casing and ream out the hole in the boulder to a size which will enable him to sink the proper casing through it. The error of mistaking a boulder for bedrock may be avoided by observing the drillings brought up to the surface and noting whether they are of material like the bedrock in the vicinity. If a boulder is especially hard, it may be blown to pieces by dynamite or rock powder, tamped with a bushel or two of dry sand or clay. This may split the boulder so the casing will pass down between the broken parts; or, it may break it into pieces so small that they can be further reduced by the drill and removed by the bailer. If the boulder is to be broken by blasting, the casing is drawn 3 or 4 feet above the charge.

(3) Running muds and clays. Mud produced from some shales hardens quickly when exposed to the air. If such mud runs into a well and fills the space between the drill and the well wall, it may solidify and interfere with the withdrawal of the drilling tools. A hole drilled through a stratum of such shale is cased down, and drilling is pushed forward so rapidly that the mud does not have time to solidify. The drill may be freed from this obstruction and withdrawn by slowly working it up and down so as to gain on the upstrokes, and the mud may be removed by small buckets or augers. If this method fails, 1½- or 2-inch pipes may be lowered into the well and the hardened mud and sand flushed out by a powerful water jet. Such a layer of mud and clay sometimes can be passed by casing it off with a short length of pipe and using a smaller drill, but the driller usually prefers to work patiently past it rather than to reduce the size of the hole by casing it off.

(4) Quicksand. (a) Character of material. In some areas the most serious difficulty is caused by beds of quicksand, which as a rule are interstratified with beds of coarser sand and of clay. The quicksand comes into the drill hole, and must be bailed out in large quantities before the casing can be driven further down and drilling continued. Under ordinary conditions, quicksand will not yield its contained water; therefore, if it has a tendency to rise in the pipe, the difficulty seldom can be obviated by pumping alone. The whole mass is saturated, its water cannot be separately withdrawn, and it exerts practically hydrostatic pressure. A driller may find pockets or lenses of clay or coarse sand in a quicksand layer, and these cause him to think he has passed through the quicksand. Coarse sand will not rise if the velocity of the water through it is less than about 2½ feet per minute. The drive pipe shuts off the water and quicksand above such a pocket of coarse sand or clay, but as soon as the drill penetrates the pocket, the quicksand flows in and may rise to the height of the top of the deposit. If the bed is 20 feet or more thick, the pipe cannot be driven through it because of the resistance of the compact sand; and, if the water in it is under great head, so as to force the sand up to or above the point at which the bed was struck, further progress may be almost impossible. In some wells, quicksand has risen in the pipe 100 feet above the depth at which it was struck.

(b) Pressure of material. If the drill hole is not kept full of water, the pressure exerted by quicksand on the well casing may be great. Quicksand saturated with water exerts a lateral pressure equal to about one-half its vertical pressure. Beyond the point of saturation the pressure is hydrostatic, the vertical and horizontal pressures being equal. Quicksand can be confined only by using water tight casing, for it is commonly so fine that it will pass a standard 100-mesh sieve. Saturated material of this

fineness flows like water. The lateral pressure of quicksand is exceeded only by that of clay, and the clay moves much more slowly.

(c) Withdrawing tools. When quicksand is encountered, not only does the material require laborious excavations but, unless the drill is withdrawn rapidly, it gets jammed in the hole and is buried by the sand. The driller then not only must clean out the hole but also recover the drill before he can resume drilling. In this event it is usual to bail out the quicksand to the point at which the drill is stuck, and then introduce into the well a wash pipe an inch or two in diameter. With this the quicksand is agitated or jetted. This operation continues until the drill is partly free, when a slip socket is inserted over its upper end and, with the assistance of the fishing jars, it is jerked free from the quicksand. In the up-and-down motion of the drill while it is being removed from the quicksand, it must be raised a little more with each stroke, and in this way gradually freed. The same procedure is required where quicksand comes into a well suddenly, the drill being moved up and down as if it were cutting into rock, while at the same time it is lightly raised at each upstroke. This operation must be carried on so rapidly the sand cannot pack about the drill and prevent its removal. Quicksand may be partly overcome by filling the bottom of the well with mortar or Portland cement, which sinks through the quicksand and sets. The hole then may be drilled through the cement, which forms a wall that prevents the further inflow of quicksand. Stones, clay, and asphalt also have been dropped or poured into the hole to restrain the quicksand, with some success.

(d) Water pressure. The head of the water in quicksand nearly always is less than the elevation of the well mouth. Some drillers maintain that quicksand can always be penetrated by keeping the drill hole full of water. If the quicksand lies at a depth of several hundred feet and its head is 100 or 150 feet below the surface, a column of water in the well will exert a back pressure on the quicksand of 43.4 pounds per square inch for every 100 feet of drill hole, which will prevent it from rising in the pipe. The sand bailer then may be inserted and the well may be bailed through the column of water. Sometimes after bailing out large quantities of quicksand, the pipe becomes bent. This is explained by assuming that the quicksand bailed out is removed from beneath a higher layer of firmer material, such as till or clay, on only one side of the pipe, and that the pressure of this material against one side of the lower end of the pipe caused it to be thrown out of alignment. The remedy consists in keeping the hole full of water. This prevents the formation of such an artificial cave; or, if the pipe already has become crooked, it corrects the trouble by causing the pressure on the pipe to be equal on all sides.

100. LOST TOOLS.

a. Causes. The loss of drilling tools in the hole usually is caused by one of the following:

(1) Broken pins. These are a common cause of trouble in percussion drilling, caused to a great extent by excessive tightening of the joints when they are made up with the tool wrenches. Crystallization as a result of drilling hard rock causes slight additional pin breakage, but this is negligible. The small 2- by 3- by 7-inch American Petroleum Institute pins, which are standard Corps of Engineers' equipment, are especially vulnerable in this respect. Only one man should be employed when the chain bar and wrenches are used to tighten these joints, and he should not exert his full strength.

(2) Tool joints, loose or unscrewed. This occurs in the hole for one reason only—imperfect seating of the pin shoulder against the box face. The efficiency of the joints depends altogether on the mating of these two points. Both the pin shoulder and the box face should be thoroughly cleaned and free of imperfections that prevent a full, even contact. Modern drilling practice is to use a small quantity of light machine oil on the threads and the shoulders when they are made up. This prevents rolling and scoring when the joints are unscrewed with the wrenches.

(3) Broken drilling cable. This usually is due to improper spooling on the bull reel drum. As this is an inherent fault in almost all small spudders, little can be done to correct it except to keep the cable and the bull reel drum well lubricated with heavy, viscous oil. This prevents damage to the drilling cable to a certain extent. Certain conditions, such as hot salt water, sometimes are destructive to wire-drilling cable. However, these are seldom encountered in shallow water-well drilling.

(4) Boulders occasionally falling in the hole. Boulders fall in the hole and wedge the drilling tools so tightly they cannot be loosened with the jar bumper. When this happens, the cable is cut with the rope knife and the tools removed with the fishing string. The tendency of shattered rock formations to "cave" or fall into the hole is greatly aggravated by the motion of the drilling tools in the water surrounding them. Usually this trouble ceases after the hole has reached a depth that places the tools below the caving formation.

(5) Broken jars. These seldom cause trouble. Breakage usually starts with a small crack in the links that eventually results in a complete fracture if use of the jars is continued. Cracks or checks in the links are easily detected by hitting the links lightly with a small hammer while they are hanging on the mast. Jars free from flaws or imperfections give off a clear, bell-like tone when struck. Occasionally a set of jars forms a bur where the upper and lower links join. This should be removed with

a chisel; otherwise the jars will be locked in their working or extended position, rendering them useless when needed.

b. Recovery. A description of fishing tools furnished with the No. 17 Star machine and a discussion of their use is given in paragraph 79.

101. SETTING SCREENS. The equipment used for setting screens in percussion holes penetrating unconsolidated material materials depends on the type of screen being installed. Below are listed three types of water-well screens ordinarily used, with a brief outline of methods and equipment used for installation.

a. Open-bottom screen (fig. 56). After the well casing has been driven down and seated on top of the water-bearing sand, the open-bottom screen is run in the hole on a string of conductor pipe, which usually is one size smaller than the well casing. When the screen reaches bottom it is worked down through the water-bearing sand to a seat by bailing through the conductor pipe. After the screen has reached the desired depth, a wooden plug is driven in the bottom of the screen with the tools. The conductor pipe then is unscrewed from the top of the screen by use of a left-hand collar and nipple, and removed from the well. The wedge block then is run in to spread the lead collar. Best results are obtained with the open-bottom screen when the lower end is threaded so a piece of blank pipe 3 to 5 feet long, equipped with a light drive shoe, can be used on the bottom of the screen. When this is done, plugging the end is much easier, and often unnecessary. This type of screen when properly constructed of wire-wrapped perforated pipe or a brass tube fitted over perforated pipe, is the most satisfactory for both rotary- and percussion-drilled wells. It is indispensable where several screens, with blank joints of pipe for proper spacing, must be set.

b. Washdown screens. These are the ordinary brass tube type of screen fitted with a one-way valve on the bottom and a lead collar on top of the screen. They are lowered in the hole with a string of pipe that is screwed into place just above the wash valve by a left-hand nipple. This nipple is necessary for detaching the screen from the pipe when the desired depth has been reached. After lowering the screen to the bottom, a mud pump is connected to the top of the wash pipe and the screen is washed into place with water or light, fluid mud. When the screen is seated at the proper depth, the wash pipe is removed and the lead collar swedged out against the casing. Usually a 20-foot length screen of this type is the maximum for any one installation in a percussion hole.

c. Flat-bottom screens. These are similar in construction to other types of screen, except that the bottom is closed with a riveted or soldered plate. They have a lead collar for sealing against the casing. There are only two methods for installing this type of screen successfully.

(1) Drive the well casing *through the water sand*, then clean out the hole to the bottom of the pipe and run the screen down on the bailer. After setting the screen in the bottom, jack or pull the pipe back so the screen is exposed to the formation. The lead collar then is swedged out against the casing.

(2) After the well casing has been seated on top of the water sand, mix mud and fill the hole to a point where the hydrostatic pressure of the fluid mud is sufficient to prevent the water-bearing sand from caving. After this is done, drill far enough into the water sand to accommodate that part of the screen which is to be exposed below the well casing. Lower the screen in the hole with the bailer, and swedge out the lead collar with the swedge block. The flat-bottom screen probably is the least desirable type, because of the difficulties and uncertainties of installation with percussion tools.

CHAPTER 9

WELL DEVELOPMENT

SECTION I

GENERAL

102. DEFINITION. The term "well development" as used in this chapter means post-drilling treatment of a well to establish the maximum rate of usable water yield.

103. DESCRIPTION. Well development is the pumping, surging, and bailing to wash the fine sand silt and clay from the water-bearing formation immediately surrounding the well screen. The removal of fine materials opens the pores and channels through which water enters the well and reduces the resistance to inflow. The maximum rate of yield and the yield per foot of draw-down are increased and the screen of coarser particles around the well inhibits the movement of fine particles into the well.

104. HYDRAULICS OF WELLS.

a. When a well is put down into a layer of water-bearing material and pumped, the water in the casing is lowered and the water from the saturated material surrounding the casing flows into the well. If pumping is continued, the water level in the well continues to sink and the water coming from the saturated material increases until it equals the discharge. The water moving toward the well passes through the pores in the sand, and the closer it approaches the well the faster it moves. The water surface formed as the result of the continuously increasing downward slope toward the well is an inverted bell-shaped depression known as the cone of

depression. *The amount that the water surface is lowered at any place near a pumping well is called the "draw-down" at that place.* It is the distance between the water level when the well is being pumped and the static water level.

b. The flow into a well depends chiefly on the draw-down of the water level and the thickness and permeability of the water-bearing stratum. Formulas have been developed showing the relationship of these factors. They are, however, difficult to apply to field conditions owing to the complexity of the phenomena involved and the difficulty of determining accurately the values of some of the variables. They indicate nevertheless certain fundamental relations that are of value in studying the behavior of wells.

c. The formulas show that the discharge from a well is directly proportional to the permeability of the material in the water-bearing stratum. The permeability increases as the coarseness of the water-bearing material increases, and decreases as the compactness increases. It also is affected by the uniformity of the material. The permeability coefficient varies through wide ranges, the value for coarse sand being several thousand times as great as that for fine sand. An artesian water-bearing formation in Utah was found to be one hundred thousand times as permeable as the overlying clay. It is important, therefore, to have as coarse a water-bearing medium as possible, and one that is free from fine material. Fine material such as silt and clay fills the pores between the large particles and retards the flow of water.

d. It frequently is assumed that the water-bearing material is satisfactory simply because it contains boulders as large or larger than baseballs. If there are no fine particles, such boulders indicate an excellent well. Usually, however, the spaces around these boulders are filled completely with graded sand, and the result is that the boulders obstruct the flow. This is shown in figure 82, which is a section of such material taken at right angles to the flow of the water. It is obvious that the water cannot flow through the large rocks, and consequently is retarded more than if all the space were filled by the same smaller particles.

e. In wells where the casing penetrates the full depth of the water-bearing stratum, the capacity of the well is directly proportional to the thickness of this stratum if the draw-down and other conditions remain the same. The deeper the well is driven into a water-bearing stratum the greater the discharge for a given draw-down. This fact frequently is neglected. Where the water-bearing formations are thick there is a tendency to limit the depth of wells due to the cost. This cost, however, usually is balanced by the savings in operation resulting from the decreased draw-down.

f. The relation of the discharge to the draw-down for the different conditions is shown in figure 83. The discharge from the well in the shallow water-bearing medium increases 80 gallons per minute when the draw-down is increased from 2 feet to 3 feet, while it increases only 40 gallons per minute when the draw-down is increased from 10 to 11 feet. It is apparent from these values that as the limit of the draw-down is approached, the increase in yield is obtained at the expense of a disproportionate increase in the draw-down. This fact is important when deciding how much water to pump from a well. In figure 83, for the same conditions in the artesian well, or the well drilled deep into a thick water-bearing formation, the increase in discharge is 100 gallons

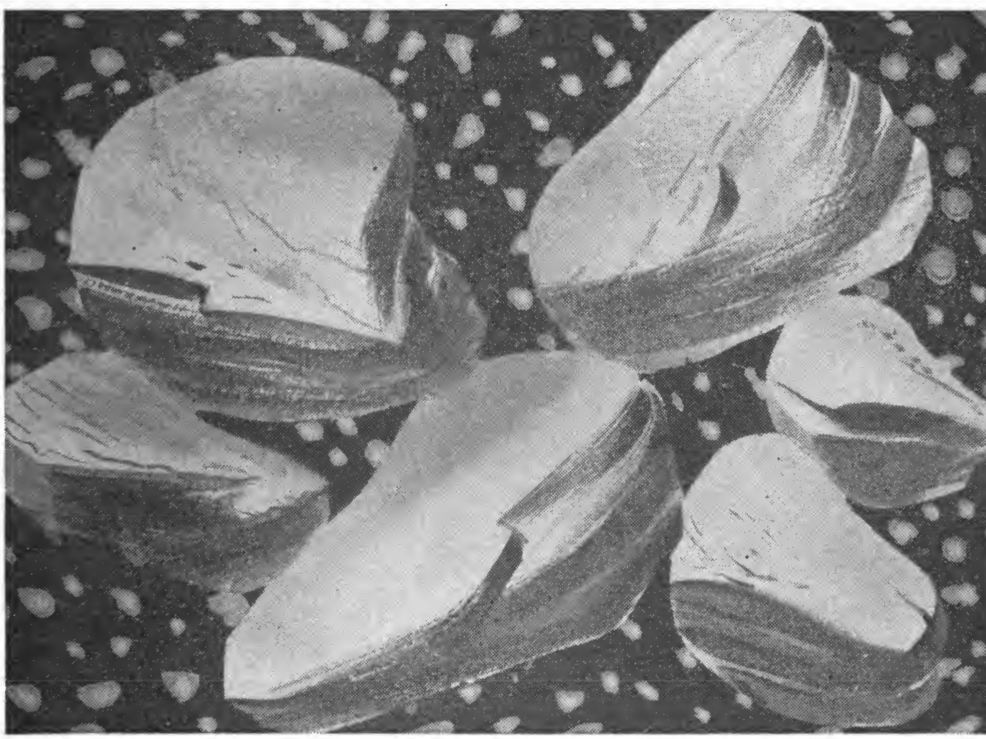


Figure 82. Cross section of water-bearing formation composed of boulders and fine sand.

per minute whether the draw-down is increased from 2 feet to 3 feet or from 8 feet to 9 feet. In this case the yield is increased without causing a disproportionate increase in the draw-down.

g. Consideration of the theoretical relations of the factors affecting the discharge from wells shows that the discharge increases as the diameter increases, but not in the same proportion. In general, doubling the diameter of small wells causes a proportionately greater increase in yield than doubling the diameter of larger wells. Small-diameter wells, 2 to 6 inches, generally are used only where the water-bearing material is permeable or where

only a few gallons of water a minute are needed. Yields of several hundred gallons a minute usually are obtained only from larger wells ranging in diameter from 6 to 36 inches. Wells larger than 36 inches in diameter that penetrate permeable materials are uncommon.

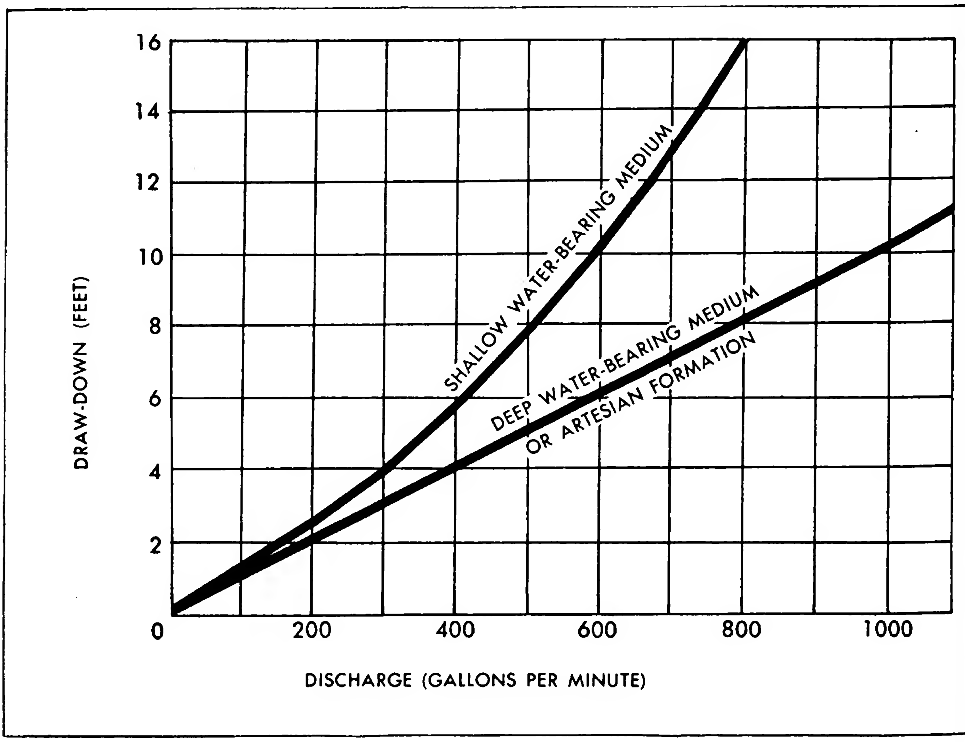


Figure 83. Discharge draw-down relation of wells.

105. SANITARY PROTECTION.

a. Contamination of a well means the entrance of harmful bacteria or toxic chemical agents into the water. In general, most contamination enters the well at the surface through the well opening; hence it is important that the space between the casing and the pump pipe be sealed tightly by an approved sanitary well seal or a suitable bushing and packing gland. For an open dug well, a watertight cover, preferably of impervious concrete, may be used. Wood covers are subject to more or less rapid deterioration, and because of constant warping and shrinking they can not be kept watertight easily. The casing should extend at least 1 foot above the general level of the surrounding surface.

b. Another place where surface pollution enters a well is around the outside of the casing or curbing. The space between the outside of the curbing or casing and the wall of the hole therefore must be sealed securely at the surface to prevent the downward percolation of undesirable water. This can be accomplished by thoroughly puddling the space around the

casing with clay and sealing the upper part with concrete. A concrete platform then can be constructed around the well.

c. Undesirable subsurface waters which contain high concentrations of mineral salts can be excluded by the proper setting of casing and screens.

SECTION II

USE OF CEMENT GROUT AND ASPHALT IN WELL CONSTRUCTION

106. ADVANTAGES OF WELL CEMENTING.

a. Because of the prevalence of corrosive ground water and ground water of quality below public water supply standards, the methods of preventing the encroachment of such water upon water of good quality are highly important. This section outlines the methods of cementing that are adapted to water-well construction to prevent the contamination of acceptable water supplies. Practically all the methods of cementing wells have been developed in the drilling of oil wells, but fortunately they can be used successfully in water-well construction.

b. The use of cement becomes much more general in constructing deep water wells in territory where undesirable ground waters are present. Cementing the casing lengthens the life of the average well and it offers excellent protection against undesirable waters and surface drainage that contaminate the supply.

107. SELECTION AND OBJECTIVES OF CEMENTING METHODS. In excluding objectionable water from a well the first requisite is to determine its source. It is obvious that water conditions in one locality are entirely different from those in another, and a method adapted to one may be unsuitable to the other. For this reason a detailed study of the particular local conditions should be made to determine the method to be used. Bearing in mind the natural factors that tend to protect ground-

water bodies against pollution, it is possible by applying certain principles of well construction to preserve these natural factors. Generally speaking, a well terminating in a free-water body conforms to the following:

a. Upper seal. It is of permanent water tight construction from a suitable elevation above the permanent grade at the well into a continuous impervious formation, or to a safe depth below the probable present or future maximum draw-down of the water level, called the dynamic water level, in the well. This is suggested in figures 84 and 85.

b. Lower seal. The opening or annular space surrounding the well casing should be sealed with a durable impervious material to prevent any movement of water through it, either upward or downward. This is indicated in figures 84, 85, and 86.

c. Casing seal. **(1)** The upper casing pipe terminal should be suitably sealed against entrance of water of any kind.

(2) By sealing the annular space surrounding the casing pipe, the movement of water through it is prevented, thereby maintaining underground conditions that tend to prevent bacteria from reaching the groundwater body. In addition, possible leaks in the casing pipe due to defects which escaped observation or which developed during construction are sealed by the grout.

(3) Properly constructed and maintained, the "drilled and cased" type of well is permanently free of pollution. Failure to seal the annular space largely is responsible for the disproportionate number of polluted wells of this type, despite proper precautions applied at the upper terminal and the sufficient depth of the casing pipe.

(4) When a well terminates in a confined ground-water body under artesian pressure, often it is essential to guard against both influent and effluent water. It is possible for water to flow from a low horizon to a pervious horizon at a higher elevation when the well is not being pumped, while the reverse condition may exist when pumping. On the one hand there may be a loss of available ground water, while on the other hand the danger of polluting the water supply is evident. Neither is desirable. It is practicable to so construct a well that this condition is eliminated. Such construction insures a safe water supply by reducing the depth from which the water must be pumped.

(5) In areas where flowing wells are common their construction should permit the inflow to be controlled. Many areas have been deprived of the convenience of flowing wells through inadequate construction and control.

(6) The general principles of construction of the drilled well apply also to the dug, bored, or drive-point wells.

(7) In water-well construction where cementing materials are not used, objectionable waters in overlying beds normally are excluded by seating

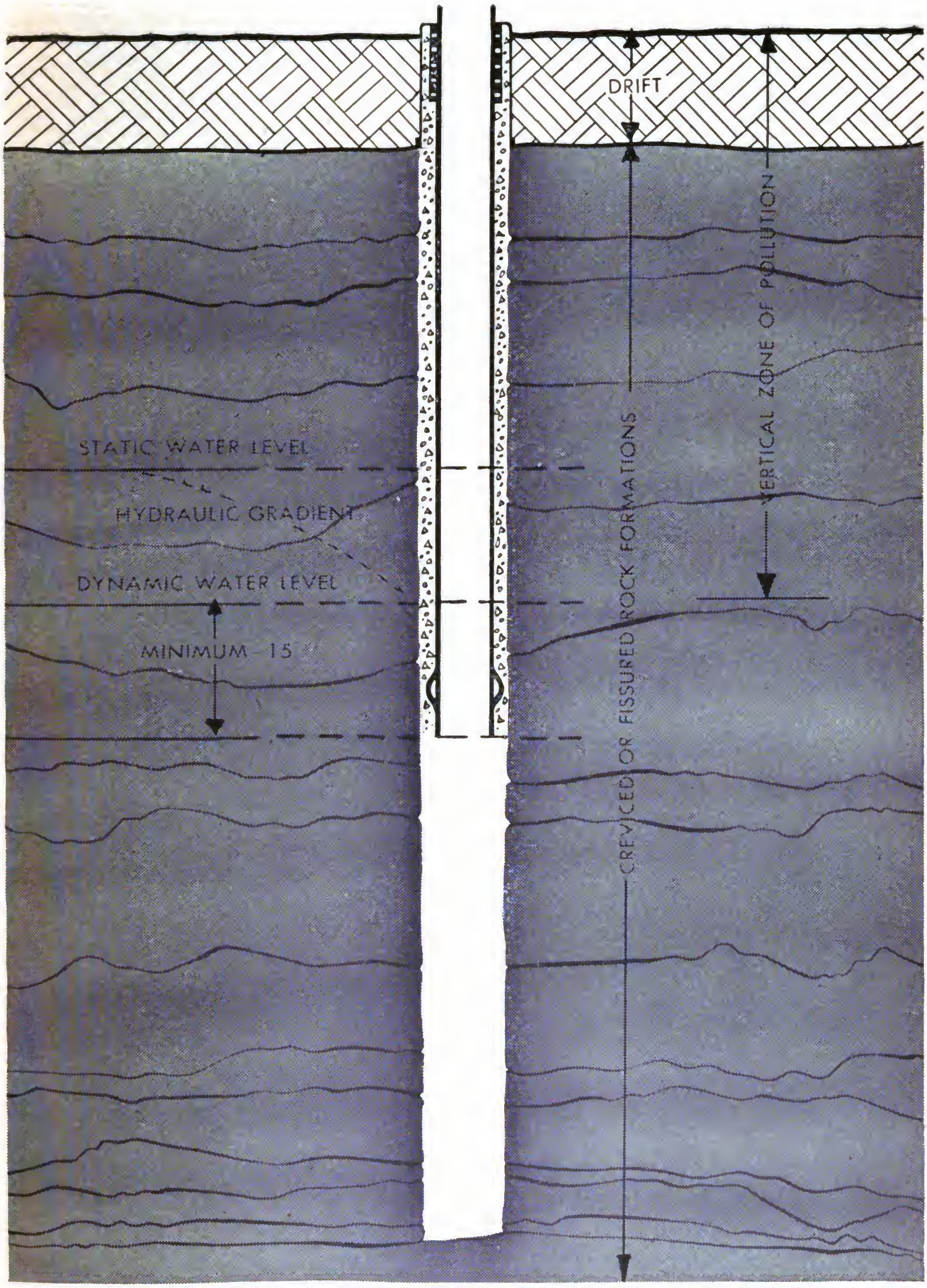


Figure 84. Construction of well in creviced rock formation.

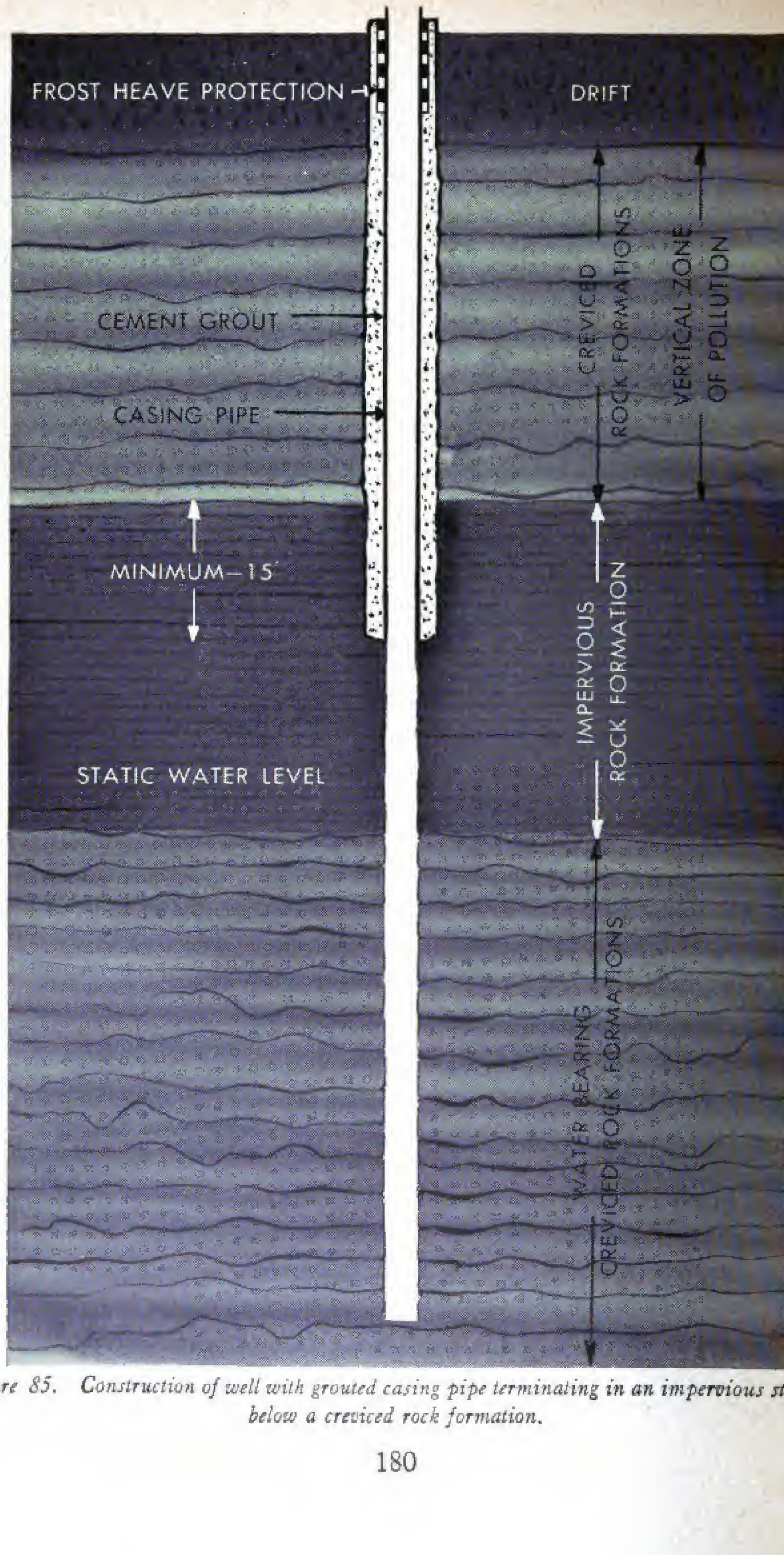


Figure 85. Construction of well with grouted casing pipe terminating in an impervious stratum below a creviced rock formation.

the casing in a relatively hard and impervious stratum, thereby shutting them off. Where this is impossible, packers frequently are used, but as the packing material normally is subject to deterioration, this method is not recommended for the best type of construction. In rotary-drilled

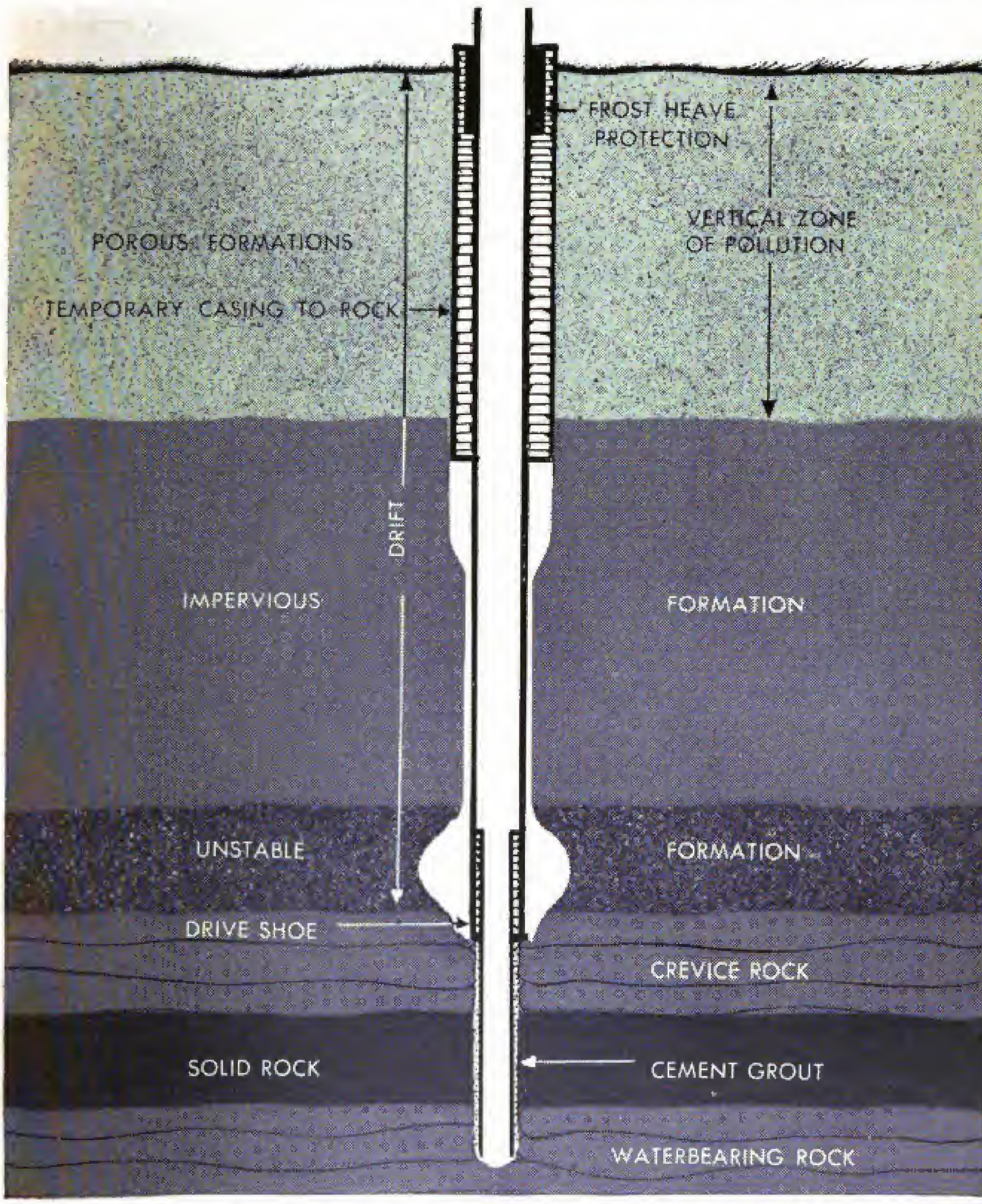


Figure 86. Treatment of annular space through drift and unstable formation.

wells heavy mud-laden fluid is circulated behind the casing, preventing circulation of water behind the casing and delaying deterioration due to the action of corrosive waters. In many localities it is impossible to find a hard and impervious formation upon which to set the casing, and under

such conditions cement is an excellent material for making a perfect seal above the water-bearing formation to be developed.

108. PREPARATION OF PORTLAND CEMENT FOR USE IN WELLS.

a. Portland cement is one of the most suitable materials for the construction or finishing of water wells. The use of cement in the construction of well curbing and well tops is familiar to most people, but its use for safeguarding the well generally is not understood.

b. Void spaces, such as the annular space between casing and hole or crevices in rock formations, are the conduits through which undesirable water and pollution gain access to a well. Either or both also may be responsible for considerable loss of ground water. These channels are difficult to reach by ordinary means, and the material used in sealing or grouting them must permit placement to serve its purpose and after placing, assume a permanent and durable form. Portland cement, properly prepared and handled, meets these requirements adequately.

c. The well driller need not hesitate to use cement for fear "something might happen" with which he is unable to cope, if he gives proper attention to relatively few and simple details. The more important of these are:

(1) The grout mixture must be prepared properly.

(2) The grout material must be placed in one continuous mass.

(3) The grout material must be placed from the bottom of the space to be grouted, upward.

d. Proper preparation of the grout mixture is of utmost importance. Best results are obtained from neat cement and water in the ratio of one bag, cubic foot, of fresh cement free from lumps, to 4½ to 5 gallons of clean, drinkable water; if necessary, up to 5½ gallons are permissible. Hydrated lime in 10 percent of the volume of cement may be added to make the grout mix more fluid and thereby facilitate placement by the pumping equipment. Mixing of cement or cement and hydrated lime must be thorough.

e. Next in importance are the proper facilities for handling and placing the grout material. Figure 87 illustrates a drill hole with a casing. The drill hole is large enough to permit insertion of a grout pipe between the wall of the drill hole and the casing pipe to within a few inches of the bottom of the annular space. The grout is pumped through this pipe, discharged from it near the bottom of the annular space, and from that point flows upward around the casing pipe until the annular space is filled. Water in the annular space moves upward before the grout, carrying with it suspended foreign particles. As the grout moves upward, it also picks up much larger pieces, such as results from caving, and

carries them to the surface. Accordingly, it is desirable to waste some of the grout which first emerges from the drill hole. The presence of loose materials makes it important that the annular space be adequate in size so foreign material does not clog the annular space and prevent or restrict movement of the grout material through it, resulting either in failure to accomplish a complete grouting job or in a defective job.

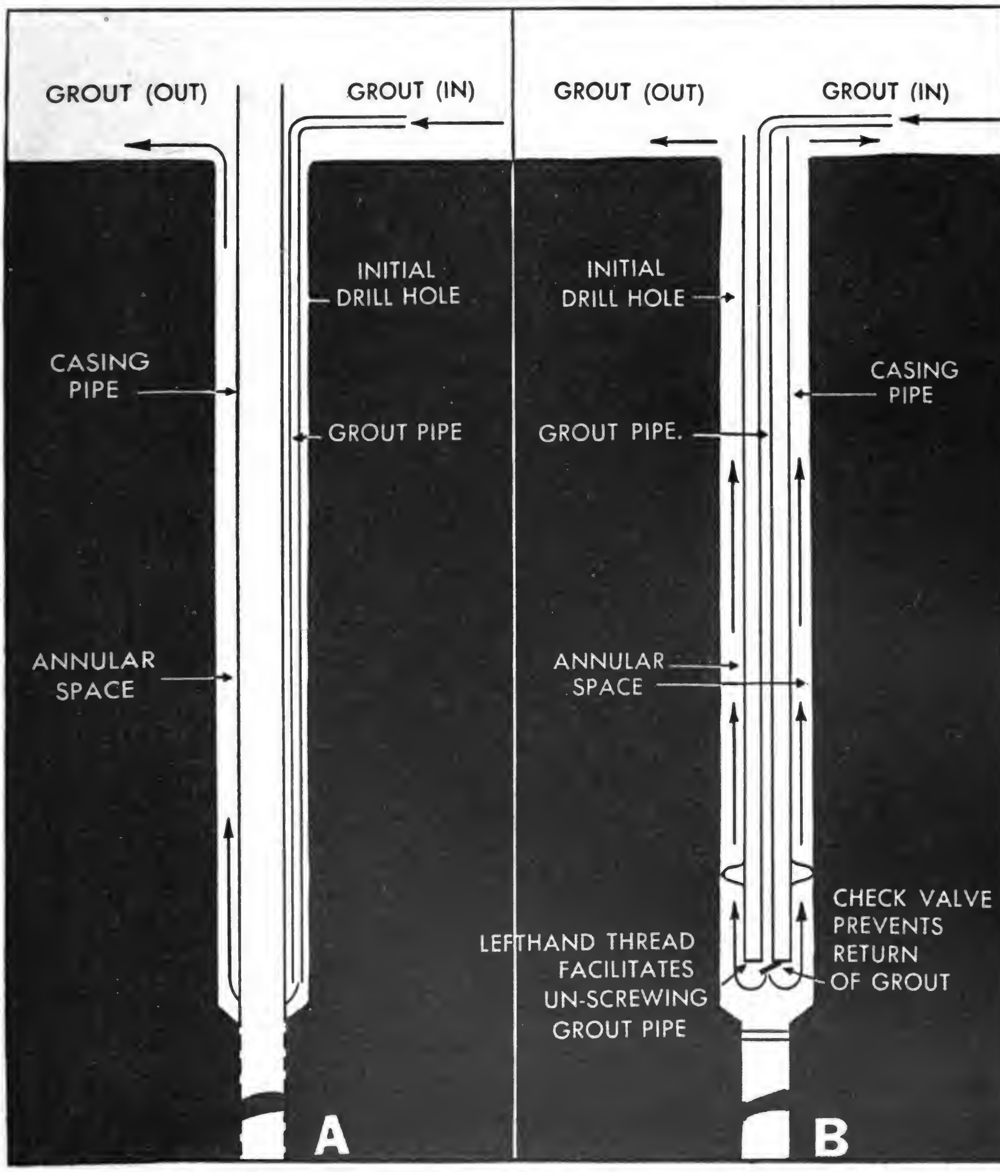


Figure 87. Piping arrangements for grouting pipe.

f. In figure 87, (A) the grout pipe is shown installed within the casing pipe instead of within the annular space as in figure 87, (B). Placement of the grout is accomplished in an identical manner. After the grout has been pumped into the annular space, however, the casing pipe is

lowered or forced to the bottom. The grout pipe is unscrewed immediately and raised several inches. A suitable quantity of water then is pumped through it to flush the remaining grout from it and the casing pipe. The grout pipe then is drawn from the well. From 3 to 7 days are allowed for setting of the grout. Then the well is cleared by drilling out the cap, check-valve, plug, and grout remaining within the well.

109. DUMP-BAILER METHOD.

a. The dump-bailer method is probably the simplest and requires the least additional equipment. In cementing a well by this process, the liquid cement is lowered in a dump bailer which discharges its load on reaching the bottom of the hole. After the necessary amount of cement has been placed in the well, the casing is pulled 20 to 40 feet off the bottom, or sufficiently far to bring the shoe above the level of the cement. The casing then is filled with water, sealed at the top, and again lowered to the bottom. Because the water is practically incompressible and there is no outlet at the top, the cement cannot enter the casing and is forced up on the outside, where it is permitted to set before uncapping the well.

b. It may be necessary to cement a well in which the water level is low and is not raised by the addition of water from the surface. If it is impossible to fill the casing with water, the column of air in the casing after the well is capped is compressed as the casing is lowered to its seat, and the cement comes up inside the casing instead of being forced up on the outside. To overcome this difficulty, several types of cement plugs have been devised to seal the bottom of the casing and to serve the same purpose as the column of water in the pipe.

c. The two plugs most generally used are the "sure-shot cement plug" and the "Hall cement plug." The "sure-shot plug" is lowered on the bailer and may be raised readily or lowered in the pipe. It does not set until it passes outside of the casing, when a set of slips are released. When the bailer is picked up the slips pull up firmly against the shoe and the plug seals the casing which then is lowered to the bottom displacing the liquid cement. The "Hall plug" accomplishes the same purpose but is set in the pipe a short distance above the shoe by an upward pull on the bailer. Both plugs have appropriate valves which open to permit the water to flow through the plug while it is being lowered into place. If the "sure-shot plug" is properly seated below the shoe, little cement normally enters the casing. If the "Hall plug" is used, 5 to 10 feet of cement generally must be drilled out after the cement has set, because it is difficult to set the plug nearer than 5 feet from the end of the casing without entailing considerable risk of getting the plug below the shoe.

110. TUBING METHOD.

a. In the second method, tubing which extends to within a few feet of the bottom of the well conducts the liquid cement to the bottom of the casing. To prevent the cement from being forced up between the casing and the tubing a packer is placed at one end of the tubing. The tubing method is summarized by Tough as follows:

"In cementing a well by the tubing method the driller should make sure that the fluid will circulate before any other work such as putting in tubing is started. If water cannot be forced from inside of the casing around the shoe and up outside of it, it is obviously useless to try to force cement through. Assuming that it has been possible to get circulation with water or mud fluid, the tubing may be inserted with the packer on the bottom. A disc packer is frequently used for such jobs, although any other type of packer meeting the general requirements will do. After the cement has been mixed and pumped in under the packer and followed by sufficient water to flush the tubing clear of cement, a stopcock, or gate, at the top of the tubing is closed, and the casing is lowered to the bottom of the hole. After the casing is thus set on bottom, the tubing, together with the packer, should be pulled up enough to free the packer before any residual cement has an opportunity to set. After the packer has been thus loosened, water is pumped down the tubing and back to the surface between the tubing and casing in order to wash out any cement from inside the casing. The tubing is then pulled with it. This done, it is advisable to completely fill the casing with water and close the top with a plug or other suitable fitting, and to leave the hole in this condition while the cement sets.

b. The chief disadvantage in using a packer at the bottom of the tubing is that the packer may leak a large quantity of cement as a result of the high pressure and it then becomes impossible to remove the packer and several of the bottom joints of tubing. A left-hand thread therefore is used to connect the packer to the tubing and insure the complete recovery of all the tubing even if the packer cannot be extracted. To overcome the disadvantage of the bottom packer, one sometimes is used at the top instead. Several types have been devised for this special purpose.

c. Figure 88 shows an arrangement for setting a short liner pipe in cement grout. Here it is desired to grout a section of the well extending to some depth below the initial casing pipe. To do this, a liner pipe is set so that it extends from the bottom of the section of the well to be grouted to above the lower terminal of the initial casing pipe to insure a watertight joint when the grout has been placed.

d. The liner pipe is prepared as indicated in figure 89, showing a suitable and inexpensive method of joining the grout pipe with the liner

pipe at the lower terminal. A check valve, grout discharge openings, and means of disconnecting the grout tube after placement of the grout also are shown. The upper end of the liner pipe is suitably flared to permit centering the liner pipe in the well and to guide the tools and equipment that are lowered into the well. The openings shown in the "flare" permit

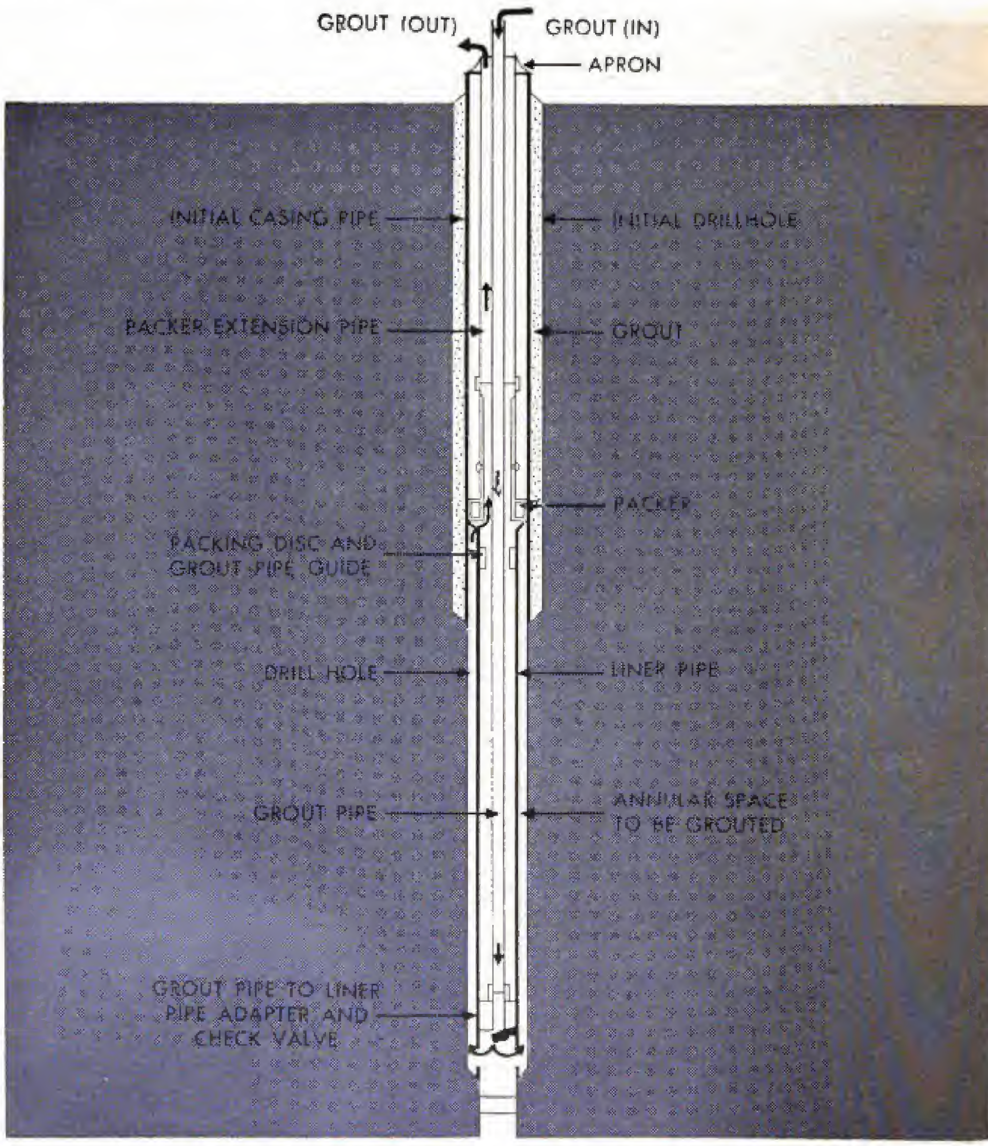


Figure 88. Grouting arrangement for short liner pipe.

escape of the grout material when the annular space surrounding the liner pipe is filled. The purpose of these openings presently will be pointed out. The wood guide block serves the dual purpose of protecting the casing and providing a seal.

e. The operation of grouting consists of pumping suitably prepared grout downward through the grout pipe. The grout material is discharged from the grout pipe through the check valve and the openings in the casing pipe, upward through the annular space until it is filled. Some grout then passes through the openings in the flare of the liner and flows upward within the packer pipe and around the grout pipe. When

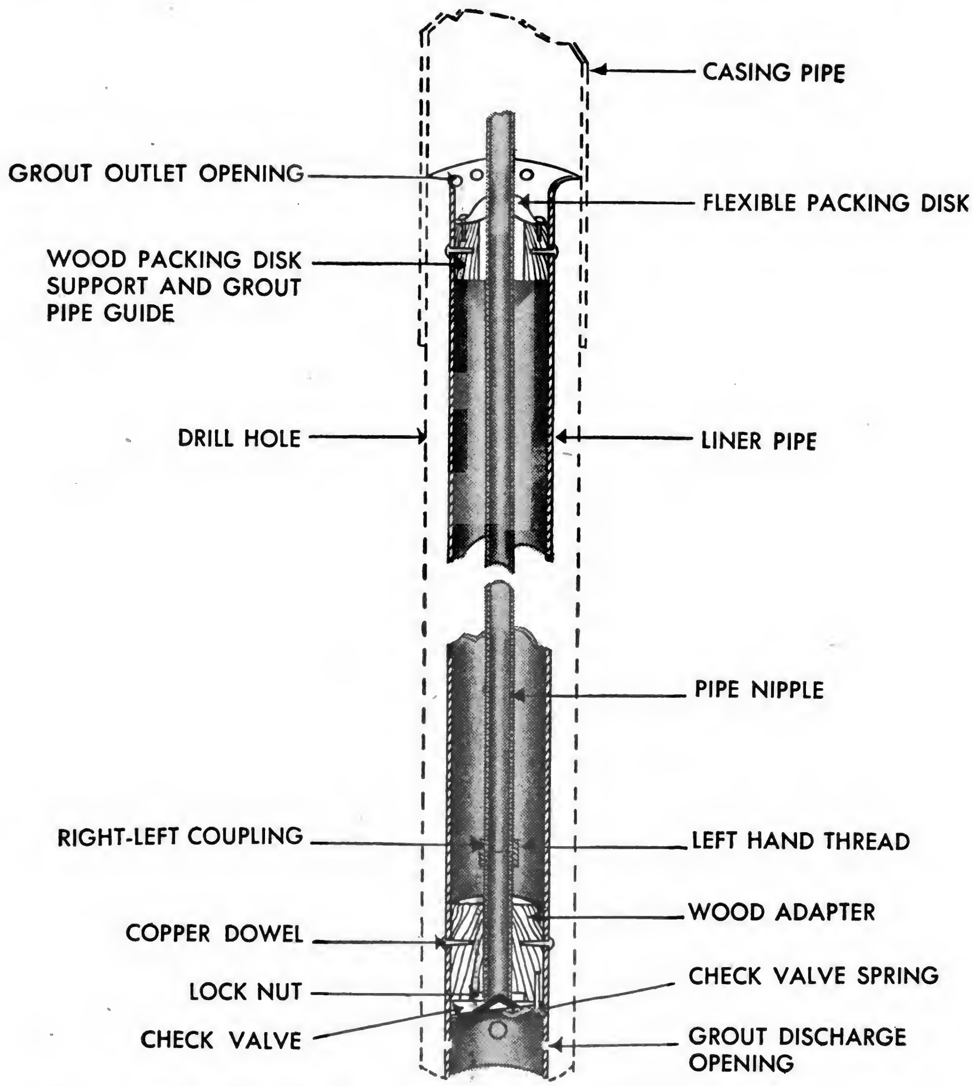


Figure 89. Detail showing arrangement of grout and liner pipe.

grout is discharged at the surface, the annular space is filled. The grout pipe then is disconnected (unscrewing at the bottom is made possible by the left-hand thread just above the adapter block) and raised about 1 foot. Water then is pumped through the grout pipe until all grout material is flushed out of the liner and packer pipes. The grout pipe and

the packer pipe are removed. From 3 to 7 days are allowed for the cement to set. The guide and adapter blocks then are drilled out. This completes the grouting operation.

111. CASING METHOD.

a. To overcome the loss of time due to the handling of tubing, the well casing is used as a conductor tube for placing the cement. This method is called the casing method and is used either with or without suitable barriers between the cement and the water. The method of using plugs between the cement and water generally is known as the Perkins process.

b. As in the tubing method, the first operation is insuring circulation behind the casing. A suitable wood plug, somewhat smaller than the casing, is used. At the upper end are two gaskets which maintain a fairly close fit in the casing. The lower end of the plug is drilled with appropriate channels permitting the cement to be forced out of the casing after the bottom plug reaches the guide shoe that usually is employed on strings of the casing to be cemented. If a guide shoe is not used, the bottom plug must be long enough to extend into the casing and act as a stop for the second plug.

c. After the plug has been placed in the casing, the fittings are attached and the necessary quantity of cement is pumped in on top of the plug. The fittings are removed and a second plug is placed on top of the cement. Water is pumped in on top of the second plug, forcing the plugs and the slug of cement down the casing. The pumping is continued until the cement is forced out of the casing and the lower plug reaches the bottom.

d. As soon as the upper plug reaches the lower one, pumping is discontinued and the casing is lowered to its seat. As no means are provided for measuring the travel of the upper plug, the quantity of water pumped in on top of the plug is measured by a water meter. If insufficient water is used, all the cement is not removed from the casing, and if too much is pumped in, water is circulated around the seat of the casing and the cement is removed, thereby preventing a perfect seal. After the casing has been landed, pressure is maintained for about 24 hours to prevent backflow of the cement. Sometimes the pumps are kept in operation to maintain the pressure and compensate for leakage.

e. Figure 90 shows a procedure that may be used when the annular space is inadequate for the insertion of a grout pipe. In principle, the method illustrated is employed and patented by the Halliburton Oil Well Cementing Company. This organization does not object to drillers using this method of cementing in the construction of the ordinary domestic water well. They expect their patent rights to be respected however when the method is applied to deep wells. Briefly, the method consists of the following: the casing pipe is suspended in the drillhole and held sev-

eral feet off the bottom. A "spacer," also called a "go-devil," is inserted in the casing pipe. The casing pipe then is capped and connected to the grout pump. The estimated quantity of grout, including a suitable allowance for filling of crevices and other voids, is pumped into the casing

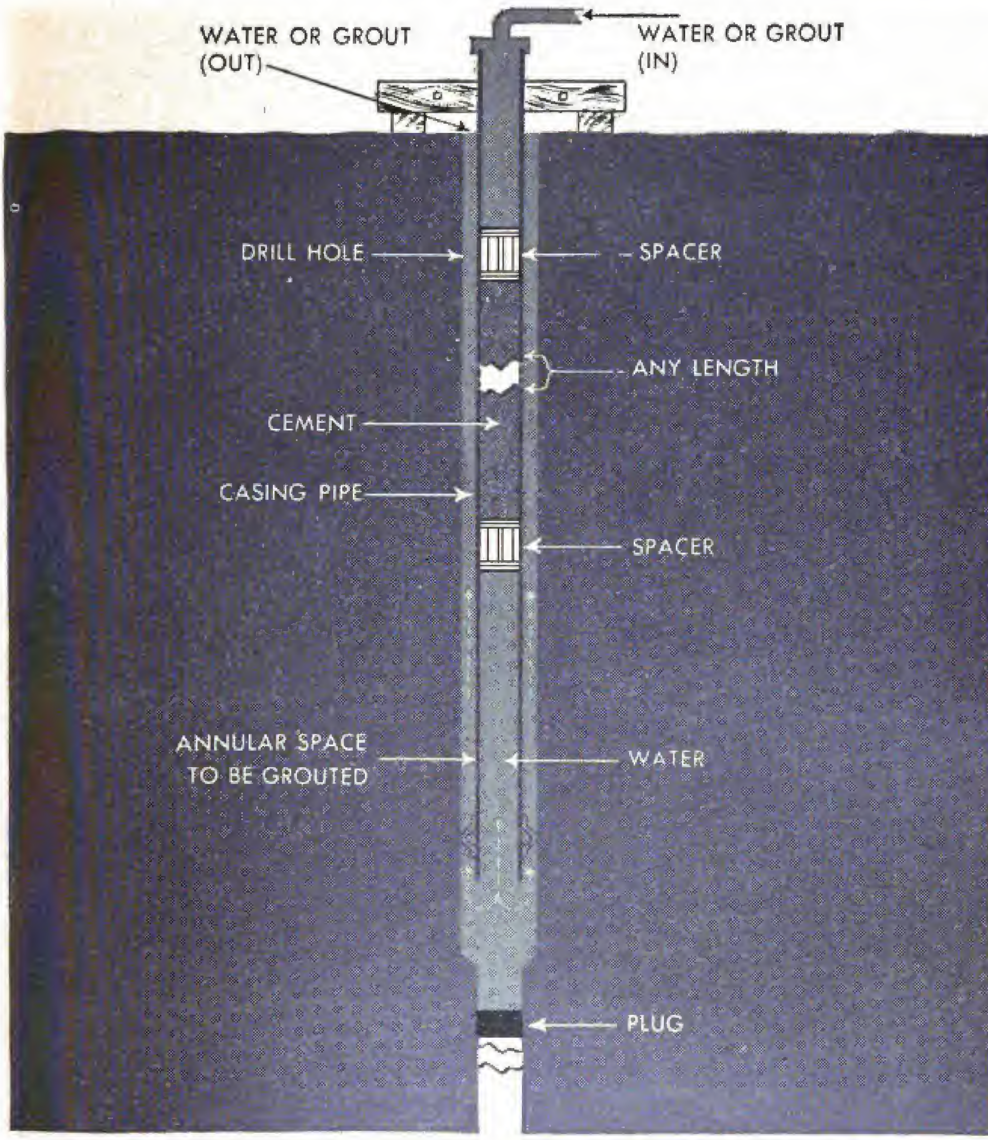


Figure 90. An arrangement for placing cement grout through casing pipe (courtesy Halliburton Oil Well Cementing Co.).

pipe. The spacer moves before the grout, forcing the water before it. Arriving at the lower casing terminal, the spacer drops or is forced to the bottom of the drill hole leaving sufficient clearance to permit the flow of the grout into the annular space and upward through it. After the desired amount of grout has been pumped into the casing pipe, the cap is removed

and a second spacer is inserted in the casing pipe. The cap is replaced and a measured volume of water sufficient to fill all but several feet of the casing pipe, is pumped into it. Thus, all but a small quantity of the grout is forced from the casing pipe into the annular space. The casing pipe then is lowered or forced to the bottom. From 3 to 7 days are allowed for the setting of the cement. The spacers and grout remaining in the casing and drill hole then are drilled out. This completes the grouting operation.

112. MIXING EQUIPMENT. Equipment for mixing and placing cement grout need not be elaborate for the operations of the average driller. It is important, however, that such equipment be adequate. In planning the equipment to be used, the driller should remember that the grout mixture once prepared, is on its way to becoming set. In other words, the grout material is placed while in a fluid state. The most favorable time is immediately after a thorough mixing. This means that freshly-mixed material should be supplied in adequate amounts to meet the requirements throughout the grouting operation. For small jobs and where no other equipment is available, an ordinary 50-gallon steel barrel serves the purpose. Twenty gallons of water is put in the barrel into which four bags of cement are sifted slowly while the water is agitated vigorously with a paddle. If a large quantity of grout is required several barrels are used. This method of mixing by hand is rapid and fairly thorough. If a concrete mixer is available, a number of batches can be mixed and dumped into a storage vat from which the material is drawn as needed while mixing continues. Continuous type mixers are more satisfactory than the batch type. The most satisfactory mixer is the jet type. Drillers who do an appreciable amount of grouting should use a mixer of this type.

113. PUMPING THE GROUT. Anyone accustomed to pumping water is likely to become alarmed when the pumping of cement is suggested. Those who doubt that it can be done should take advantage of the first opportunity to see it done. It is true that not all water pumps are suitable for the purpose. The valve arrangement and passages in the smaller pumps are inadequate; and the speed of small motor or engine-driven pumps is entirely too high. Many of the larger slow-speed reciprocating water pumps are used without modification. It is unnecessary, however, to risk the possible clogging of ordinary water pumps as there is ample equipment available which is entirely suitable for the purpose. For instance, diaphragm pumps, combined lift and force type, handle up to 3 cubic feet of fluid per minute under a pressure head of 20 pounds per square inch. This is ample for practically every grouting

operation the average driller has to do. The cost of the equipment is moderate. Jetting pumps usually are constructed to handle ordinary grouting jobs. Combination mixers and placers utilizing compressed air for mixing and placing the grout material also are available. The amount of cement required depends upon the formations through which grouting is done. Generally, an allowance of from 25 to 100 percent in excess of the calculated amount should be available. To this must be added a suitable allowance for absorption of grout material by crevices, fissures, and pores in the formations to be grouted.

114. ASPHALT SEALING. Although cement has been the material most generally used in sealing undesirable water-bearing strata, several methods for using heated asphalt recently have been developed. Such processes generally are similar to the use of cement with tubing. In addition to the pump equipment, provision is made for heating the asphalt material so it may be handled under pressure and forced into place before it cools. The processes appear to offer several good features for use in water wells, particularly in sealing off the flow of artesian water so cement will set.

115. PLUGGING WELLS. Mud fluid and cement are the most effective materials for plugging a well for producing from formations above the bottom. Under some conditions, these are the only materials that afford proper protection. A well always should be plugged from the bottom rather than bridged above the bottom in an endeavor to shorten the job. To prevent the entrance of possible bottom water, a cement plug preferably is set at the bottom. A minimum of 10 sacks of cement should be used, and dumped with the dump bailer. If water under artesian pressure enters from the bottom of the well, first it is necessary to stop the movement of the water, or the cement will not set and form an impervious seal. The artesian movement may be prevented by placing a plug of lathe turnings, lead wool, or pieces of cable, that have been burned to draw the temper. This material may be lowered into the well in tin canisters and then tamped in place by a blunt tool. After the movement of the water has been stopped, the cement plug is placed in the usual manner.

SECTION III

PRINCIPLES AND METHODS OF DEVELOPING WELLS IN SAND AND GRAVEL

116. RELATION OF SLOT SIZE TO GRAIN SIZE OF SAND. Recent practice shows that a proper screen size is that which excludes about one-third of the sand in which the screen operates. The screen is not merely a strainer but more properly is a device supporting the bore hole in the water-bearing formation to prevent it from collapsing or clogging while freely admitting water. In contrast, a well ending in an open pipe gives the least area of contact with the formation.

117. BASIC REQUIREMENTS FOR SCREENS. The first consideration in developing a sand or gravel well is a screen or stabilizer which makes available all of the area of opening possible. The second requirement is a screen adapted to the process of development without clogging. These are important requirements because water cannot pass through the solid parts of the screen, and the screen's failure to pass the fine material without clogging eliminates the proper development of the formation.

118. DEVELOPED OR NATURAL GRAVEL-PACKED WELL. A screen is inserted in the water-bearing formation at the bottom of the well and sealed to the well casing. A single line of well casing is used, and no provision is made for the artificial insertion of gravel. Some method of pumping and surging is provided. As the finer material is pulled through the slots of the screen, all but the coarsest material next to the screen is removed. Then the finer material in the second zone moves to the first zone; that from the third zone moves to the second zone; that from the fourth zone to the third zone, and so on. As this is continued, the sand grains gradually arrange themselves with the largest and most

uniform only, next to the screen; the largest and next smaller size, in the second zone; and the largest and next two smaller sizes, in the third zone, and so on. The mixture is more uniform and more permeable as the screen is approached, and with each zone graded in relation to the one beyond it so each acts as a stabilizer for the one outside it. Regardless of how hard the well is pumped this relationship will not be disturbed, though the nature of each zone may be changed.

119. ARTIFICIAL GRAVEL-PACKED WELL.

a. In graded material. A coarse aggregate is inserted directly around the screen, which is set into a water-bearing formation having a mixture of coarse and fine material. As soon as pumping is started, finer material moves into the coarse material, and since there is a mixture of coarse and fine in the formation, the coarse is held back and the fine is pulled into the packing gravel. To be successful, this method requires the same features in the well screen as in the natural gravel-packed or developed well and requires surging for best results.

b. In fine material. (1) If too coarse a pack is used in fine sand, the fine material moves into the coarse material, filling the voids between the coarse grains and reducing the permeability. The aggregate, being too coarse and not extensive enough, cannot build up a graduated wall of assorted sand and gravel around the screen. The only remedy is to replace it with finer aggregate or to increase its range of texture. This is usually a difficult and expensive task. Figure 91 illustrates the fundamental difference between the natural gravel-packed well and the artificial gravel-packed well.

(2) Fine uniform sand is best when artificially gravel packed. A mixture of coarse and fine sand or gravel is best finished with naturally developed pack, using as coarse a slot of screen as an accurate analysis of the material shows to be advisable. It is desirable that the screen be constructed with a sharp outer slot which abruptly widens inwardly, making it possible to draw the finer material through the screen without clogging or obstruction.

120. CONSTRUCTION OF GRAVEL-WALL WELLS.

a. Under this heading are included all wells constructed by placing gravel around the screen to reduce draw-down and eliminate fine sand. As the same results sometimes can be obtained at less cost and with more certainty by other methods, the real problem is determined by the formation itself and whether or not it requires gravel treatment. Sand full of clay and silt can be gravel treated, but it must be done properly. The chemical nature of the water to be pumped also is important as the screen corrodes or becomes encrusted under certain conditions.

b. The gravel-wall or gravel-packed well (fig. 92) is used widely in developing water from water-bearing formations consisting chiefly of unconsolidated sand and gravel. This well is of greatest value, however, where the water-bearing formation is composed of fine sand in which the individual grains are approximately the same size. Under such conditions a well that is finished with a screen that is not gravel packed requires a screen with a fine slot to hold out the sand. An extremely fine slot prevents the maximum quantity of water from entering the well.

c. The general method consists in sinking the hole to the required depth and setting in it a large-diameter casing extending from near the

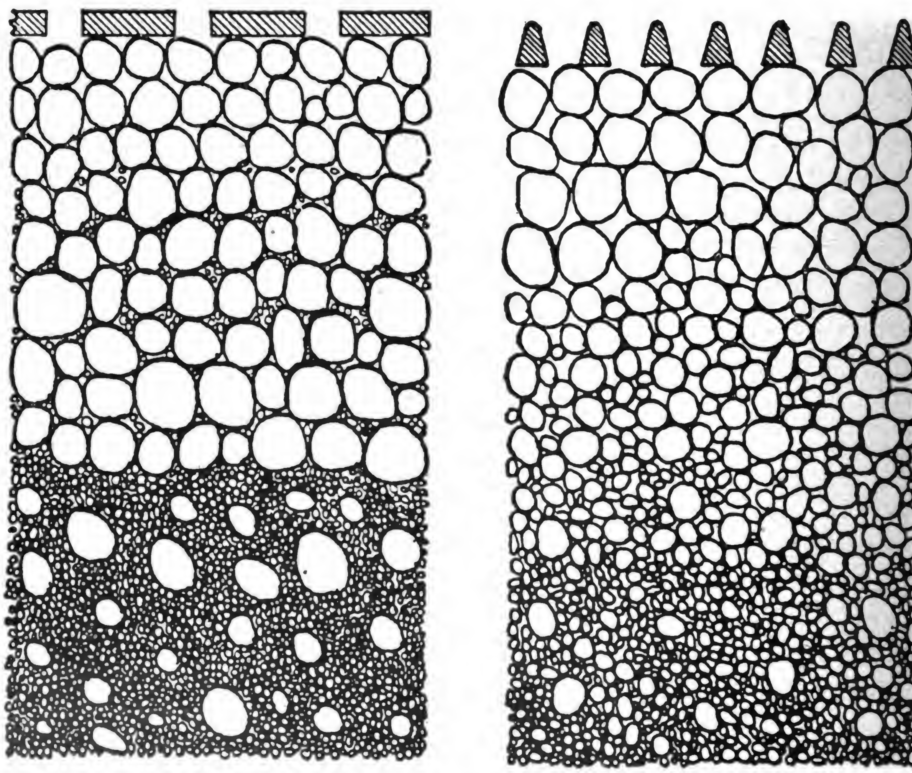


Figure 91. Arrangement of grains in gravel-packed wells.

top of the water-bearing formation to the ground surface. A well screen smaller in diameter than the outer casing then is placed in the hole opposite the water-bearing formation and screened gravel of uniform size is fed into the well between the outer casing and the casing attached to the well screen. As the gravel is placed, the well is developed so as to remove the fine sand in the vicinity of the screen, and create a pocket filled with gravel fed from the surface. If sufficient water is not supplied by the well during the course of development, additional water is added from the surface.

d. The deeper gravel-wall wells of large diameter usually are constructed by the hydraulic rotary method of drilling, and the hole is drilled and

mudded through the water-bearing formation. After the casing is landed, the screen is set and the development of the well follows in the usual manner during the process of inserting gravel. If the well is shallow and no hard formations are to be penetrated, the entire hole may be sunk by the sand bailer or sand pump. When this method is used, the hole is cased as it is deepened and the screen is bailed to the required depth after the outer casing has been landed. Another construction method is to sink

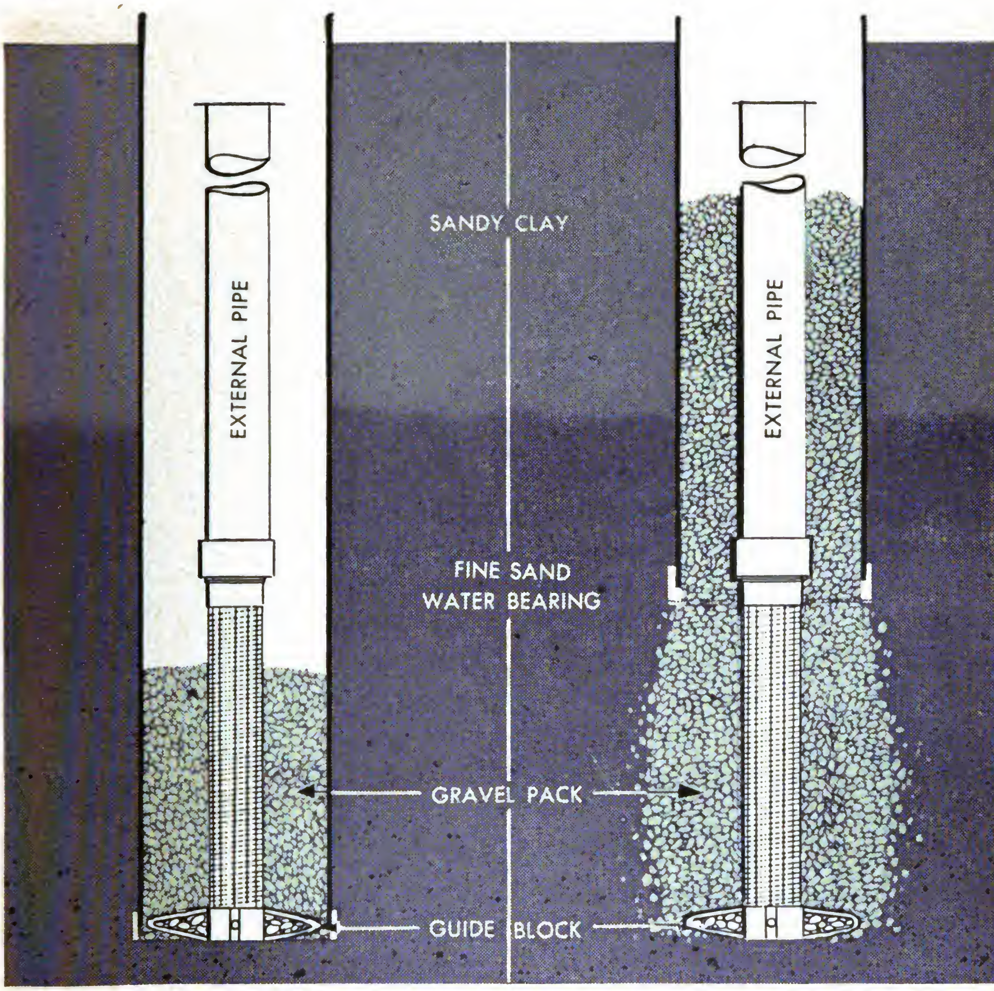


Figure 92. Gravel-wall well with casing in place. *Figure 93. The completed gravel-wall well.*

the large outer casing to the required depth in the water-bearing formation, set the screen (fig. 92), and then expose the screen by jacking back the outer casing as gravel is fed into the well (fig. 93). This arrangement insures that the gravel is placed properly. While the gravel is being added the casing is raised slowly so as to carry from 6 to 10 feet of gravel between the screen and casing. If the formation has a tendency to heave, the filling may be more than 10 feet, if the screen and casing are not sand-

locked. Sometimes water is used in the filling pipe to avoid bridging of the gravel, or it may be necessary to work the feed pipe up and down.

e. When a gravel envelope is used in connection with a well drilled by the hydraulic rotary process, the gravel is added after the perforated casing has been installed and while the clay deposit is being washed from the walls of the well. The gravel fills the space between the casing and the sides of the hole and prevents the wall of the well from caving when the clay lining has been washed off.

f. When the gravel envelope is put in while the well is being drilled, the usual practice in shallow wells is to excavate the well down to the level of the water keeping the well's diameter somewhat larger than the casing which is to be used. The casing is set in this hole and the space between the casing and the sides of the hole is filled with gravel. As the sinking of the well proceeds, sand is pulled into the well through the perforations and under the bottom of the casing. This material is replaced by the gravel which works down as the casing sinks, As the level of the gravel around the casing is lowered more gravel is added.

g. Another method used when drilling deep wells where the water table is at a considerable distance below the surface, is to drill several holes near the well at such an angle that they will intersect the bore of the well at about the water surface. Then as the drilling proceeds, gravel is fed into these holes, and as the sand around the casing flows into the well it is replaced by gravel that comes down through the holes around the well. Either method of getting the gravel to the water level is satisfactory.

h. The use of "pilot holes" (fig. 94) is another method of placing an extended gravel pack around a well screen. The well is drilled and the screen and casing set by either the rotary or percussion methods; smaller holes without screens then are put down around the central well for the feeding of gravel into place around the screen as the well is developed.

i. The underreaming method is also used for gravel treatment of wells (fig. 95). The hole is drilled to the top of the desired water-bearing formation, usually with the rotary machine, the casing is set, and then an underreamer is used to drill a large-diameter hole below the casing. After the screen has been placed in the bottom of the well, gravel is placed around the screen as the well is developed.

121. DEVELOPMENT OF WELLS BY OVERPUMPING AND BACKWASHING.

a. Overpumping. (1) Overpumping means pumping the well with excessive draw-down. If the well is strong when first brought in, this may involve pumping beyond the desired capacity with relatively little draw-down; if the well is weak, it may mean pumping it nearly dry. This

method clears the well at or below its natural capacity with only a relatively small amount of development, because the difference in head produced even with excessive draw-down is not great in comparison with that produced by other methods of development. When the well is pumped in so-called tubular manner, in which the pumping plunger is the size of

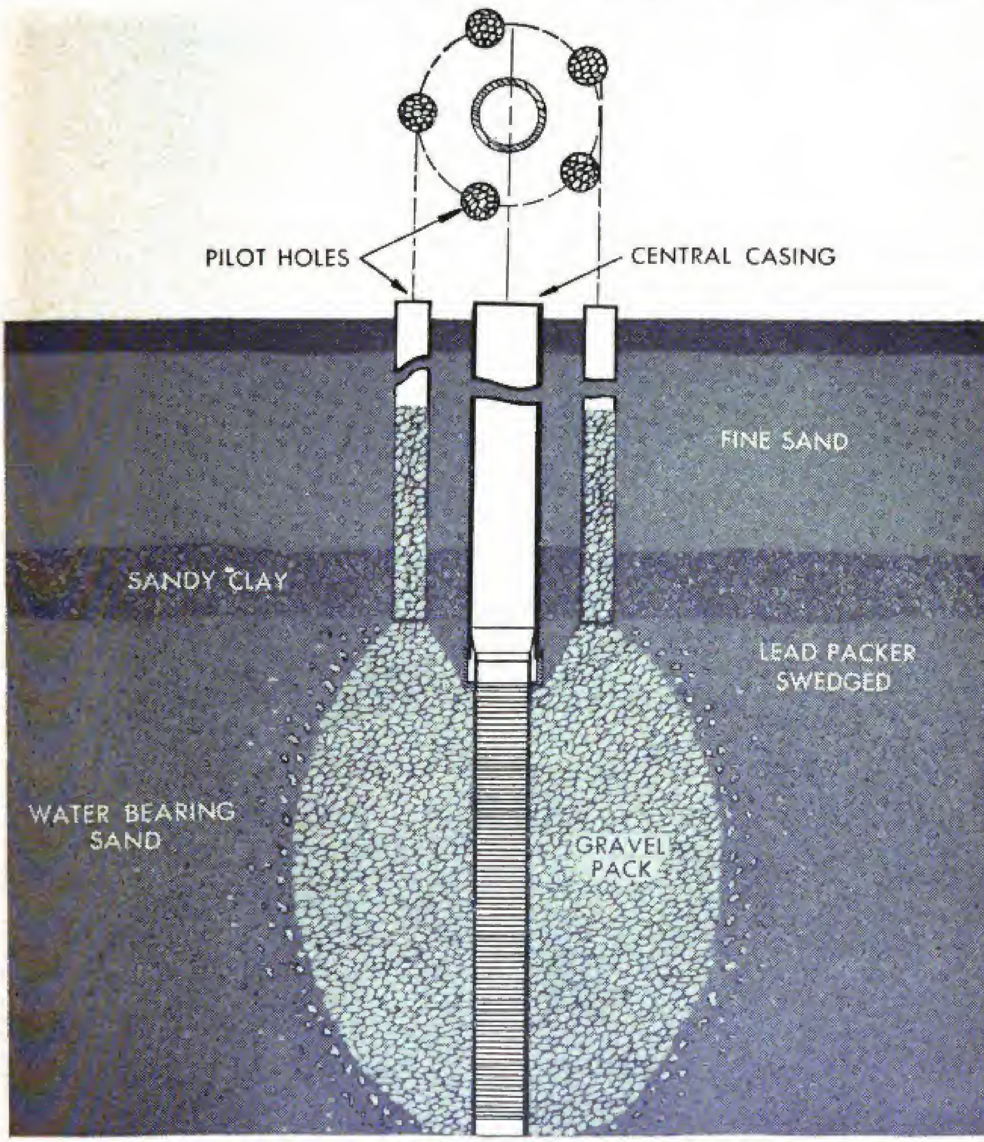


Figure 94. Pilot-hole method of gravel treatment.

the casing and works directly in it, there may result some surging effect, and a greater head may be produced by a partial vacuum established in addition to the draw-down head.

(2) "Bridging" of sand in water-bearing formations is a very important factor. When the water is pumped out of the well, there is a tendency

to move the sand in the direction of the well; and with a steady pull in this direction, the finer sand grains wedge against each other and bridge across openings or voids between coarser grains. The only way in which this can be prevented is by keeping the water agitated, pumping at the same time or intermittently. Since not much agitation can be accom-

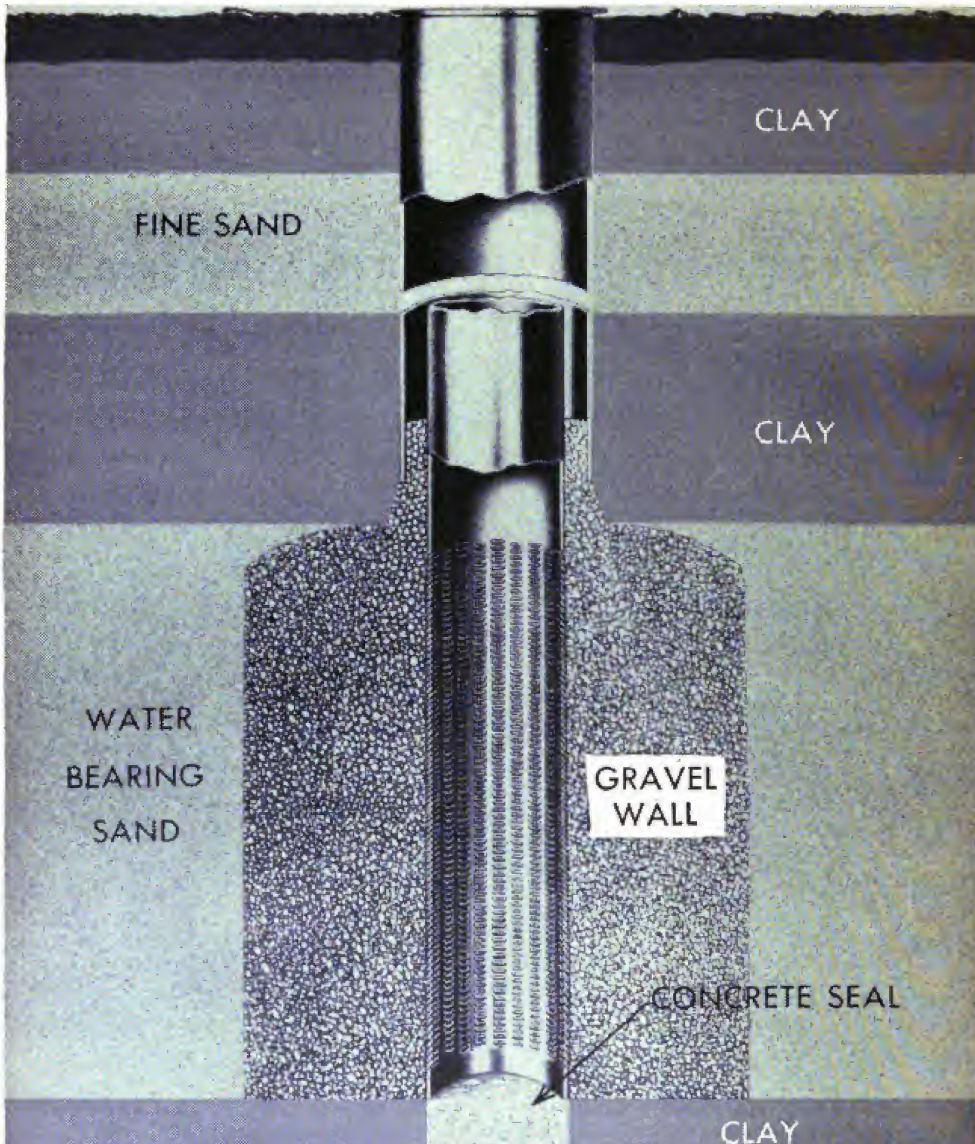


Figure 95. Underreamed gravel-wall well.

plished by direct overpumping, objection may be raised against this means of development.

(3) Overpumping may be used to clear a well successfully and is a valuable means of finishing under some conditions. On the other hand, when capacity may be increased by thorough development, other more

effective means should be used. This statement holds equally true whether the well delivers the desired quantity of water or not, because thorough development of formations capable of development reduces draw-down at any given capacity and provides a safeguard against pumping sand at a later period under heavier draft.

b. Backwashing. (1) General. Backwashing is the term applied to a number of different methods of well development, all of which are based on the principle of surging or agitating the formation at the well by hydraulic or water pressure to prevent "bridging" of the sand particles and to remove a large portion of the finer material. There are so many different ways of doing this work that no attempt will be made to cover them all in detail. One effective means is called "rawhiding the well." This consists in starting and stopping the pump intermittently to produce relatively rapid changes in the head in the well. While this may be done with any kind of pump, it is most effective with a deep well centrifugal pump (commonly called turbine pump) installed without a foot valve. There are three distinct reactions which can be obtained by operating the pump in different ways, and the effects of these are worth detailed consideration.

(a) The pump is operated at its fullest capacity until it has produced the greatest possible draw-down of the water level. It is then stopped, the water receding rapidly out of the column of the pump, and the well being permitted to regain its full static water level. This procedure is repeated many times until the well shows no further improvement.

(b) The well is pumped to obtain maximum draw-down, and the pump is then stopped and started alternately in short intervals. This has the effect of holding down the water level in the well and frequently agitating the formation by the backwash of the water in the pump column. The rapid changes from start to stop, with resultant changes in pressure head, velocity head, and direction of flow at the bottom, produce a relatively forceful treatment of the water-bearing formation.

(c) The well is pumped until the water discharges at the surface. Pumping is then stopped and the water allowed to recede from the pump column. The process is repeated. No effort is made to draw the water level as low as possible or to hold it at a low point. The object of this method is simply agitation of formation.

(2) Backwashing with bailer. Another simple means of developing by backwashing consists in pouring water into the well as rapidly as possible and then bailing out with sand pump or bailer. This produces a greater head in the well and changes the movement through the screen and water-bearing formation when the water is poured into the well. The faster the water is poured in, the greater the velocity out through the

screen and the more agitation in the formation. Likewise, the more rapidly the water is bailed out, the more vigorously the fine material is pulled into the well. Most of the bailing water can be used over again if it is screened or is dumped into a settling tank having a baffle-board permitting the sand to settle out.

(3) Backwashing under pressure. Probably the most forceful method of backwashing a well is by forcing it to take water at a higher rate than normally it will take, thus placing a positive pressure on the well in addition to that caused by the difference in the water levels of well and formation. Obviously this is a forceful method, but it may require very large quantities of water. There are two principal ways in which this method is applied:

(a) The first is simple backwashing, followed by bailing or pumping. This is done by connecting a pump of a hose line from a standpipe to the casing by means of a watertight fitting. Water is then forced down into the well in as great volume as possible and under as high pressure as can be built up. This causes a very positive reversal of flow through the screen, the water backing into the formation for a considerable distance. After the pressure has been applied for a short time, usually not more than 2 to 5 minutes, the connection is removed and the well is bailed vigorously.

(b) The second way to apply this method is by providing the top connection with a side valve outlet and a fitting to suspend a line of pipe down to the bottom or near the bottom of the well. By this means pressure may be applied directly to the well, as in the preceding means, and then the side outlet may be opened and the well flushed hydraulically. With sufficient water to create the necessary velocity, the well can be backwashed, surged, and partially cleaned in this way. Where conditions are favorable, this is a fairly effective means of development; many drillers have used it successfully on both large and small wells.

122. USE OF SURGE PLUNGERS.

a. General. The surge plunger or surge block is one of the most effective devices that has been produced for developing wells in sand and gravel formations. Although some other processes have special advantages under certain conditions, surge plungers of various types are the best known combination for average conditions.

(1) The percussion drilling machine is equipped with a valve type surge plunger (fig. 44); the rotary machine, with a mission swab (fig. 44). A swab is similar to the surge plunger and secures the same results.

(2) Surge plungers may be defined as any plungers, pistons, or blocks operated in the casing of a well to surge the water in the sand or gravel formation in order to loosen the finer sand or gravel grains and carry them

or aid in carrying them through the screen slot and into the well. The sand or gravel grains are removed from the well by any convenient means.

b. Types. Surge plungers may be classified into two general types, solid and valved. Both types may vary in details of design. For example, some have cupped leather or rubber facing; others flat leather or rubber disks. There are many different ways in which these may be made.

(1) Solid surge plungers. (a) General. Solid surge plungers are operated up and down in a well casing for the purpose of exerting equal or approximately equal force on the inward and outward movement of the water through the screen. This relatively rapid and forceful stirring of the water disturbs the finer sand particles and hence prevents their bridging against each other and thus closing the voids or openings between the larger grains or pebbles.

(b) Operation.

1. In operating a surge plunger the tools are lowered into the casing until the plunger is about 15 feet in the water. It is not necessary to lower it farther, unless greater submergence is required to prevent forcing the water out of the well faster than it is pulled back. In any event, care is taken not to lower the tools so far that they batter the top of the screen. The fact that the water cannot be compressed makes the surge plunger just as effective at the upper end of the water column as at the bottom near the screen.

2. When the tool is lowered into place in the well, the machine is set on long stroke and the plunger worked up and down in the casing so as to surge the water back and forth through the screen. The surging is started slowly and the speed increased until it reaches the fastest limit at which the tools will drop and rise without too much slap of the cable.

3. After the surging has been continued as long as the driller considers advisable, the tools are hoisted and the bailer is run into the well to clean it thoroughly. Much of the success of the method depends upon the bailer and the bailing procedure. The best type of bailer for this work is the sand-pump type fitted with a good plunger.

4. After the bailing has been done, the surging tools are run back into the well and the surging procedure is repeated until the well is fully developed, as evidenced by the fact that little or no more sand can be pulled into the screen. The total time required may range from 1 hour on small wells where the sand is very uniform to 1 week or more on large wells where an

extreme range of fine sand and coarse gravel indicates the desirability of an unusually low percentage of retention and a very large slot opening.

5. When used with rotary or other rigs not equipped to produce an up-and-down stroke by beam or spudder, the plunger may be operated by hand-tripping a rope on a drum or "cat-head," passing it over the derrick sheave. The pipe-handling equipment on most such rigs is easily adaptable for surging. The surge plunger also can be operated on the sand line.

(2) Valve type surge plungers. (a) General. There are conditions under which solid surge plungers do not work as effectively as a plunger fitted with a valve. This is especially noticeable in wells finished in formations giving small yield. To meet such problems a great many different kinds of valve plungers have been devised. They range all the way from weighted bailers with ring washers to large brass pumping plungers with partially closed waterways. The percussion drilling machine is furnished with valve type surge plungers; and the rotary machine, with valve type swabs that operate in the same manner as the surge plunger.

(b) Principles of operation. The most important feature of this type of plunger is the fact that it produces a greater inrush than outrush of water. Sometimes the inrush is too great in relation to the outrush, resulting in bridging and partial clogging. If so, the well is backwashed hydraulically or surged with a solid surge block. A valve type surge plunger may be transformed into a solid surge block by stopping the valve.

123. DEVELOPMENT OF WELLS WITH COMPRESSED AIR. The use of compressed air in the development of wells is, under favorable conditions, a rapid and effective process. There are two general methods: the backwashing method, and the open-well or surging method.

a. Backwashing method. (1) General. The principle of the backwashing method is to force the water back out of the well, through the screen, and into the water-bearing formation by means of compressed air introduced into the well through the top of the casing after it has been closed. To prevent airlogging the formation provision is made to prevent the air from entering it. This method is best used after the well has been cleared as completely as possible with the bailer.

(a) Figure 96 shows one type of hook-up that has been used successfully for this method of development. The top of the casing is closed airtight with flanges and a gasket. The upper flange is a flat blank flange into which two holes are bored off-center to provide clearance for a drop pipe in the well and for convenient connection of fittings. The smaller hole is tapped for any desired size of small pipe, commonly a 1-inch pipe.

The larger hole is drilled sufficiently large to clear the drop pipe. A tee of this size is then brazed or welded to the flange over the hole.

(b) A drop pipe is extended down into the well, with the upper end connected to the lower end of the tee. The length of the drop pipe depends upon the heading, if possible, but it is not considered good

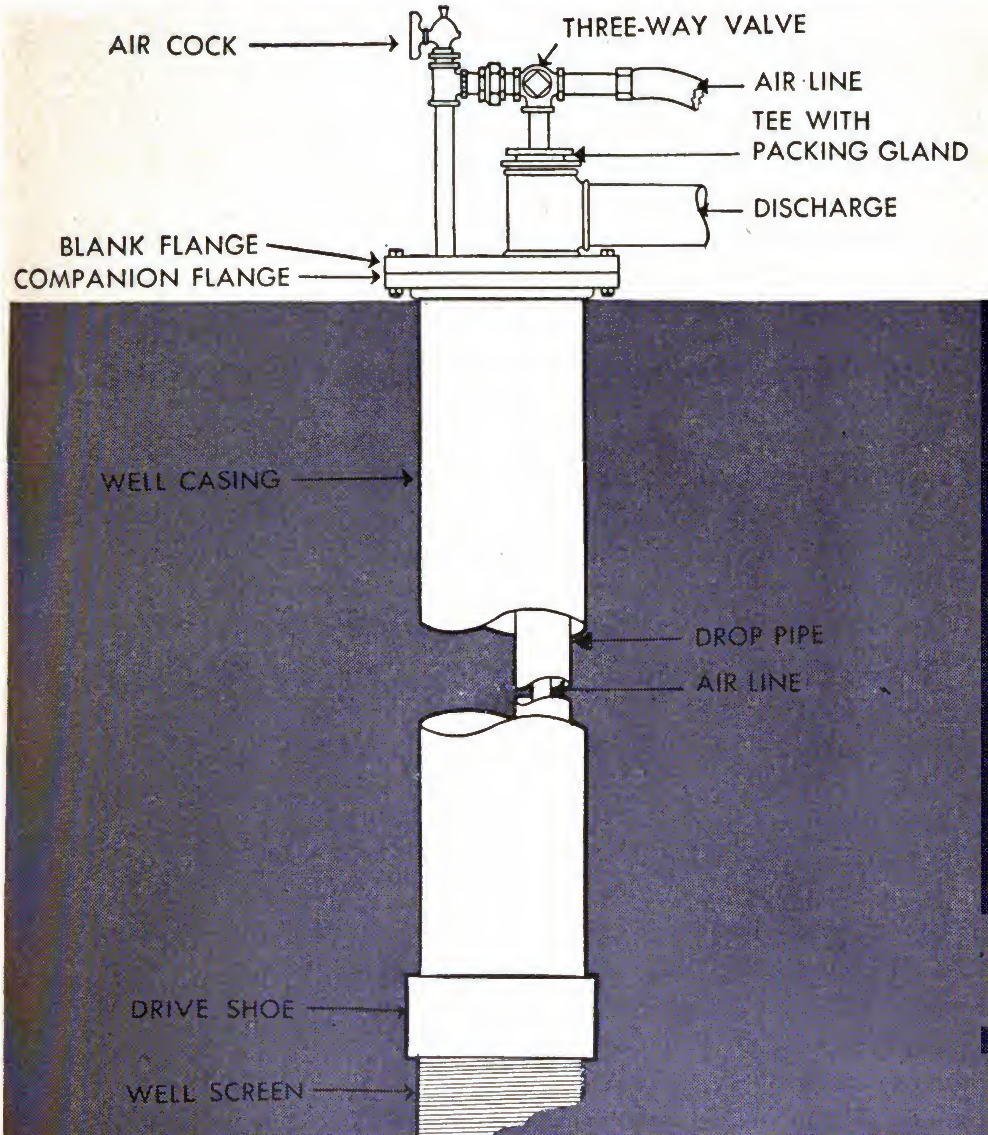


Figure 96. Details of hook-up for closed-well method of developing wells with compressed air.

practice to extend the drop pipe down into the screen during development. If necessary for purposes of submergence the drop pipe may be extended into the screen when this hook-up is used as a pump. It is good practice to extend the pipe down to just above the screen during development, regardless of submergence, in order to clean the sand out as thoroughly

as possible. By submergence is meant the extent to which the pipe is submerged in the water. Thus, for example, if a drop pipe 100 feet long extends 65 feet into the water when the well is pumping, the submergence is 65 percent.

(c) The upper end of the tee is provided with a packing gland through which the air line is passed down to a point within 1 foot or so above the bottom of the drop pipe, the distance depending upon whether or not a foot-piece is used on the air line. The side outlet of a three-way valve is connected to the upper end of the air line. The inlet of the three-way valve is connected to the air delivery line, and the end outlet is connected to a tee from which a pipe leads to the small hole in the flange. The tee also has an air cock at the other opening, as shown in the illustration (fig. 96).

(2) Sizes of pipe lines. The size of fittings used depends upon the quantity of water to be pumped, the size of the well and the depth of setting. Under average conditions the sizes shown in table III may be used with this type of unit, providing the size of the well permits. The cross-connection for the air leading from the three-way valve to the flange need not be larger than 3/4 inch or 1 inch, regardless of the size of the air lines, because it is very short and is used only during development.

(3) Method. (a) In development the three-way valve is turned to deliver air down the air line, with the air cock preferably open. This pumps water out of the well through the discharge pipe. When the water comes clear, the supply of air is cut off and the water in the well is allowed to regain its static level, which can be determined by listening to the escape of the air through the air cock as the water rises in the casing. The air cock is then closed and the three-way valve turned to direct the air supply down the bypass to the top of the well. This forces the water out of the casing and back through the screen, agitating the sand and breaking down the bridges of sand grains. When the water has lowered to the bottom of the drop pipe the hydraulic connection is broken thus making it impossible to airlog the formation.

(b) When the air is heard escaping out of the discharge pipe, or when the pressure stops increasing, the supply of air is cut off and the air cock is reopened to allow the water to reach static level. Then the three-way valve is turned and the air supply again directed down the air line to pump the well.

(c) This procedure is repeated until the well is thoroughly developed. It is seldom necessary to bail the well after this, as the velocity of the water usually cleans out the sand brought into it. However, if the well was not bailed reasonably thoroughly at first to remove the first large "slugs" of sand, these may be too heavy for this type of air lift to clean out properly.

b. Open-well or surging method. (1) Equipment required. The equipment for this method of development consists of the following:

(a) Air compressor of proper size, with air receiver of 15 cubic feet capacity or more.

(b) Drop pipe and air line in well with suitable means for raising and lowering each independently of the other. The casing itself is sometimes used instead of a separate drop pipe, although this is not the best practice.

(c) Flexible high pressure hose and pipe line to connect tank and airline in well.

(d) On the tank a relief valve large enough to safeguard against accidental overloading—that is, unless the compressor is fitted with "unloaders."

(e) Small fittings, such as pressure gauge and a quick-opening valve at the outlet of the tank.

(2) Necessary conditions. (a) For successful development by this method it is necessary to have a ratio of submergence of at least 60 percent. Except for possible excessive starting and working pressures, there is no upper limit for submergence in development of a well by this method. The static submergence may be nearly 100 percent and is best when over 65 percent. The efficiency of the work drops off rapidly as the submergence becomes less than 60 percent. In deep wells with a considerable head of water above the bottom even though the submergence is low, effective work can be done by "shooting heads," as will be described later. If both the head and submergence are low, this method of development is not of much value.

(b) The principle upon which development is accomplished is a combination of surging and pumping. The sudden release of large volumes of air produces a strong surge by virtue of friction and inertia. Pumping is as with an ordinary air lift. It is upon the skillful application of this combination of surging and pumping that the success of the work depends.

(3) Hook-up of equipment. (a) Figure 97 shows the proper method of placing the drop pipe and air line in the well. The drop pipe may be conveniently handled with a chain attached to the drilling cable; and the air line, by connecting to the bailer line if a cable-tool rig is used. A tee at the top of the drop pipe is fitted with a short discharge pipe at the side outlet, and at the top a bushing is placed to clear the couplings of the air line. A sack is wrapped around the air line where it enters the drop pipe to prevent the water from spraying about the top of the well.

(b) The discharge of the compressor should be piped direct to the tank without any valve in the line. The discharge from the tank to the well should be the full size of the air line in the well, or, if long, the next larger size, and should be fitted with a quick-opening valve near the tank. A

heavy hose is used between the discharge pipe from the tank and the air line in the well. This hose should be at least 15 feet long to allow enough space for moving the drop pipe and air line up and down. A 30-foot length of hose, as used in jetting or hydraulic rotary drilling, commonly is used.

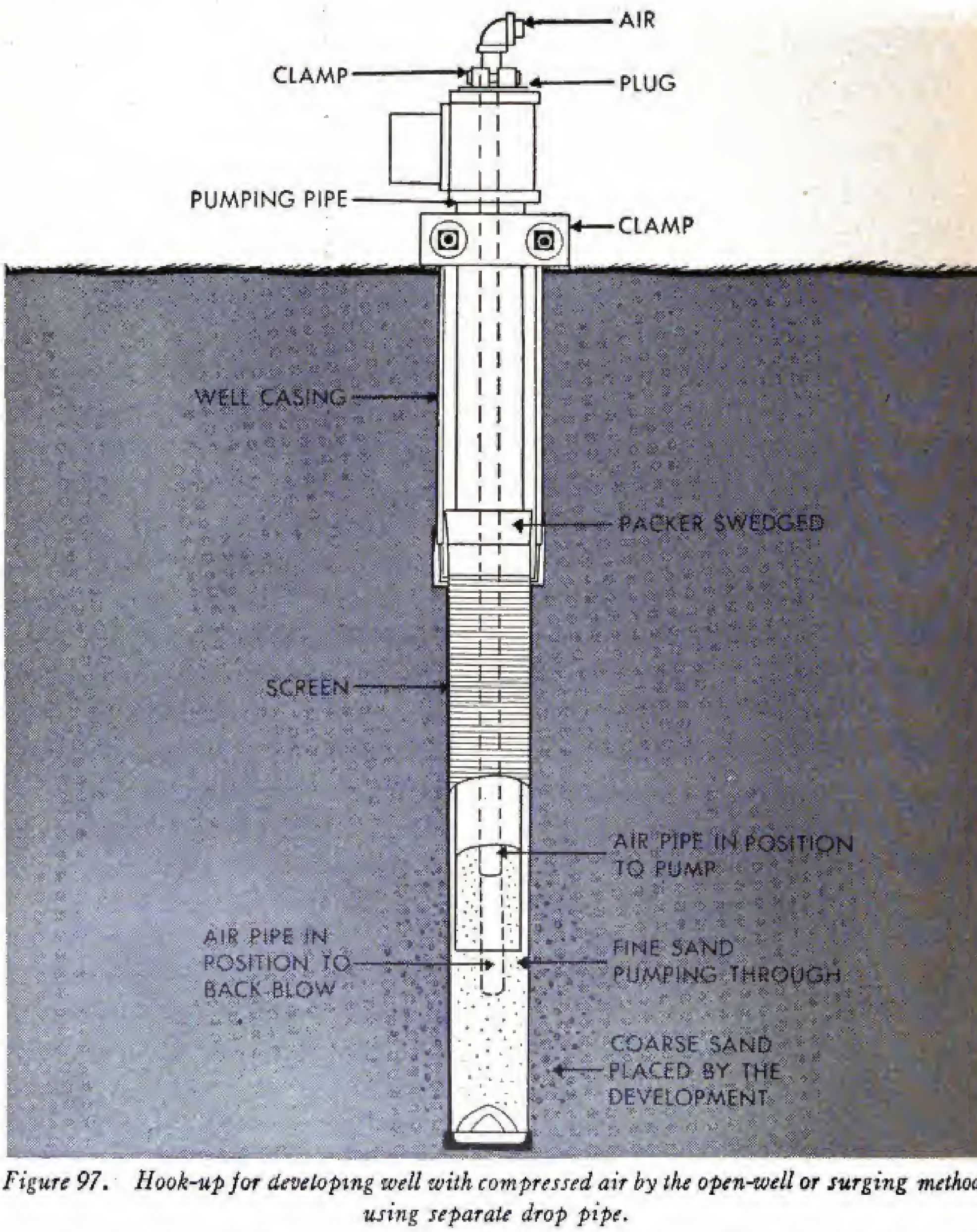


Figure 97. Hook-up for developing well with compressed air by the open-well or surging method, using separate drop pipe.

(c) At the start of development the drop pipe is lowered to within about 2 feet of the bottom of the screen. Then the air line is placed inside the drop pipe with its bottom 1 foot or more above that of the drop pipe. If there is enough submergence, the air line needs to be lowered only far

enough to get 65 percent or 70 percent submergence. The air is turned into the air line and the well is pumped in the manner of a regular air lift until the water appears to be free from sand. The valve between the tank and the air line is then closed, allowing the tank to be pumped full of air up to a pressure of from 100 to 150 pounds. In the meantime, the air line is lowered until it is 1 foot or so below the drop pipe. The quick-opening valve is then thrown open, allowing the air in the tank to rush with great force into the well. There follows a brief but forceful surge of the water, and then a head of water "shoots"—partly from the casing and partly from the drop pipe. If the air line is pulled back into the drop pipe as soon as the first heavy load of air has been shot into the well, there is a strong reversal of flow up the drop pipe; and this quite effectively agitates the water-bearing formation.

(d) The well is then allowed to pump as an air lift for a short time, and then another head is shot. This procedure is repeated until the absence of further sand shows that the development is complete at this point.

(e) The drop pipe is then lifted to a position 2 or 3 feet higher, and the same procedure is followed at this point. In this way the entire length of the screen is developed, a few feet at a time. It is then advisable to return the drop pipe to within 1 foot or 2 of the bottom of the well and to shoot one or two heads at this point. The well then is pumped as an air lift with the airline pulled up into the drop pipe. This completes the work and thoroughly cleans out any loose sand.

c. Size of compressor. **(1)** Where the air lift is to be used for the permanent pumping unit, the size of compressor, power unit, and other equipment should be determined carefully and accurately to obtain the maximum efficiency. With equipment merely for developing a well, however, there is no necessity for accuracy. It is necessary only to make reasonably close estimates of the requirements for doing the work properly.

(2) The compressor should be capable of developing a maximum pressure of not less than 100 pounds per square inch, and preferably 150 pounds. For capacities of displacement up to about 75 cubic feet per minute, a vertical one- or two-cylinder compressor usually is most economical and convenient. This size takes care of small wells very nicely.

(3) If possible, the pumping capacity should be 20 to 40 percent greater than the capacity at which the well is to be pumped. When this cannot be provided, the development must be somewhat longer and more in heads.

d. Size of pipe lines. **(1)** With wells of 4-inch diameter and smaller, sizes ordinarily used for capacities of less than 50 gallons per minute, it is customary to use the casing as the delivery pipe rather than to install a separate drop pipe. A 3/4- or 1-inch air line is used. Even in

larger wells this is sometimes done. The chief objections to doing so are less accurate control over the development, especially in wells with relatively long screens; somewhat lowered efficiency if the well is large in proportion to volume of air and pumping rate; and less accurate determination of draw-down and more difficulty in measuring the depth of water, unless the top of the casing can be fitted with a tee to direct the water into a discharge pipe. The best way to determine the draw-down when pumping in this way is to make a note of the starting pressure, which is the indicated pressure required to start pumping, and deduct from this the pressure when pumping, multiplying this difference by 2 1/3 to change it from pounds to feet.

(2) Where drop pipe and air line are used table III shows the sizes which may be used to best advantage.

Table III. Sizes of drop pipes and air lines for various capacities

Pumping rate (gal. per min.)	Diameter of well casing (inches)	Diameter of drop pipe (inches)	Diameter of air line (inches)
30 to 60	3½ or larger	2½	¾
60 to 75	4½ or larger	3	1
75 to 100	5 or larger	3½	1¼
100 to 150	6 or larger	4	1½
150 to 250	8 or larger	5	1½
250 to 400	8 or larger	6	2

(3) In development work some variation from these sizes is entirely permissible; but a great variation produces poorer results, especially if much larger quantities of water are pumped.

124. CORROSION AND INCRUSTATION OF SCREENS.

a. When selecting a well screen the possibility of corrosion and incrustation and their effect on the metal of the screen should be considered. All ground water is more or less corrosive or incrusting, depending on the substances it contains in solution. Often the two terms are confused, and a considerable knowledge of chemistry and the electrochemical theory of corrosion is necessary to understand properly these phenomena. However, the well driller can recognize the difference without such knowledge, for incrustation is a building up or depositing of minerals on and around the screen. It is not particularly harmful to the screen itself; rather it tends to protect the screen from corrosion. The harm comes from the fact that the screen and the voids in the surrounding formation are clogged by deposits of mineral salts brought in the water being pumped. The actual cause of the depositing of the salts is the change in pressure that takes

place at a well screen. As it flows along through various formations, ground water picks up and carries in solution all of the mineral salts it will hold under certain pressure conditions. When this mineral-laden water reaches a well and the pressure is reduced by the lowering of the water level from pumping, the gases holding the mineral salts in solution are released and the salts are deposited. The water also may carry silt, clay, and colloidal matter in suspension; or it may carry iron-forming bacteria. When such water reaches the well, the material in suspension may accumulate in and around the well screen.

b. If carbonate or sulphate salts are present in the water, little can be done to prevent incrustation. This is particularly true if ferrous screens such as iron or steel are used, for we then have corrosion to contend with as well as incrustation.

(1) The best remedy is to reduce the rate of pumping and thus reduce the differences in pressure. If, however, this is impossible, all that can be done is to clean the screens by removing the deposits. If the screen is constructed of a metal that will withstand acid treatment, it can be acid treated in place. If acid treatment is not effective, the screen may have to be removed and cleaned by mechanical means.

(2) Ordinarily, if properly administered, acid treatment is sufficient. The procedure is simple. If the deposits are of the carbonate or soft type, the screen is filled with ordinary commercial hydrochloric acid, commonly known as muriatic acid, placed through a small pipe from the surface. This acid is allowed to remain in the screen from 1 to 2 hours; then the well is gently surged for several minutes and allowed to stand for 2 hours or more; and finally the screen is bailed clean and the well pumped for at least 1 hour. If there is a decided improvement in yield, the process may be repeated for better results. Never become discouraged if a single application does not produce the desired result.

(3) If the incrustation is of the sulphate or hard type, more strenuous methods must be used, and a stronger acid such as sulphuric must be substituted for muriatic. In all acid treatment place the acid into the screen and leave it in long enough to accomplish its work. Always use precaution in handling acid. Ordinarily it comes in carboys holding about 12 gallons and weighing approximately 125 pounds. The amount of acid required per foot of screen is shown in table IV.

Table IV. Amounts of acid to use for cleaning screens of various sizes

Diameter of screen (inches)	Acid per foot of screen (gallons)	Diameter of screen (inches)	Acid per foot of screen (gallons)
2	0.18	8	2.60
3	.40	10	4.10
4	.66	12	5.90
6	1.50	16	9.60

(4) The use of swabs, brushes, scrapers, etc., inside an incrusted screen is not generally effective. Dry ice has been used by some familiar with its physical and chemical characteristics, but it is not recommended for general use.

(5) Remember that the rate of corrosion is increased when the velocity of the water over the metal surface being corroded is increased. No metal or alloy resists corrosion completely. Some have more corrosion resistance than others under bad conditions. If possible, it is recommended that a sample of the ground water be analyzed for its corrosive or incrusting tendencies before the screen metal is selected, for there is little that can be done to prevent or even retard corrosion once it has started.

125. STERILIZATION OF WELLS.

a. Sterilization is a phase of well construction often neglected. Practically all newly constructed wells are contaminated and should be sterilized promptly after completion. The easiest way to do this is to prepare a chlorine solution as follows: Mix one heaping tablespoonful of chlorinated lime with a little water to make a thin paste, being sure to break up all lumps. Then stir this paste into 1 quart of water. Allow the mixture to stand a short time. Then pour off the clear liquid. The chlorine strength of the solution is about 1 percent; 1 quart of the liquid is enough to sterilize 1,000 gallons of water. Larger quantities of the sterilizing solution may be prepared in the same proportion and if placed in sealed containers, preferably glass, can be stored for a reasonable length of time without losing their effectiveness.

b. Estimate the volume of water in gallons standing in the well, and for each 1,000 gallons pour 1 quart of the sterilizing solution into the well. No harm is done if too much solution is used, and it is better to use too much than too little. Agitate the water in the well thoroughly and let it stand for several hours, preferably over night. Then flush the well thoroughly to remove all of the sterilizing agent. The well casing can be sterilized by returning the water to the well during the first part of the flushing, thereby washing the walls of the well with chlorinated water.

Just before completion of the flushing, a sample of the water may be taken if required. The same solution may be used to sterilize well casing or pumping equipment that has been used or laid in the open until contaminated.

c. A well may be chlorinated under pressure or by merely introducing a strong solution of chloride of lime into the well with a bailer. The first procedure is probably the more effective, but it requires special pumping equipment. Such equipment usually is not available with percussion machines, but is with rotary ones. Under most conditions chlorination by introducing the solution with the bailer is adequate; but if contamination still exists after a thorough pumping following the dosing of a well in this manner, chlorination under pressure may then be desirable, provided the hydrostatic head is not excessive.

126. PULLING WELL SCREENS BY SAND-JOINT METHOD.

a. General. The most common reasons for pulling well screens are—

(1) Incrustation of a nature which cannot be treated successfully with acid.

(2) Corrosion which has partially destroyed the screen and resulted in sand-pumping. In such cases it is advisable to pull the old screen rather than drill it out because chunks of the lead, metal, or castings may interfere with *bailing* a new screen into place.

(3) Abandonment of the well where it is desired to recover the screen for use in another location.

It must be borne in mind that the screen is almost certain to be set very tightly in place, and in order to remove it safely an even distribution of pressure should be applied to all parts of it. This holds true regardless of the type of screen, because a grip in one place is not safe or dependable. The only exception is with screens in 2- and 2½-inch wells which usually are too small for the practical use of the sand-joint method. However this method has been used even in these small sizes.

b. Proper procedures. Figures 98 and 99 show the principles of the sand-joint method. The procedures illustrated in these two sketches differ only in details. The principle is exactly the same. The steps are as follows (see fig. 98):

(1) Sacking is wired securely above the coupling at the lower end of the pulling pipe and then cut into strips from 2 to 4 inches wide, depending on the size of the well. The sacking is to form a foundation upon which the sand-joint is to be built up; it is cut into strips to permit it to conform more perfectly to the inside of the screen.

(2) The ends of the sacking are drawn up around the pipe and tied in place. The pipe is then lowered into the well until only the upper

ends of the sacking are exposed. The string is then cut to loosen the upper ends of the sacking and the strips are arranged evenly around the pipe. The pipe is then lowered to the bottom of the screen, care being taken to keep it as evenly centered in the well as possible.

(3) Sand is then poured down the space between the well casing and

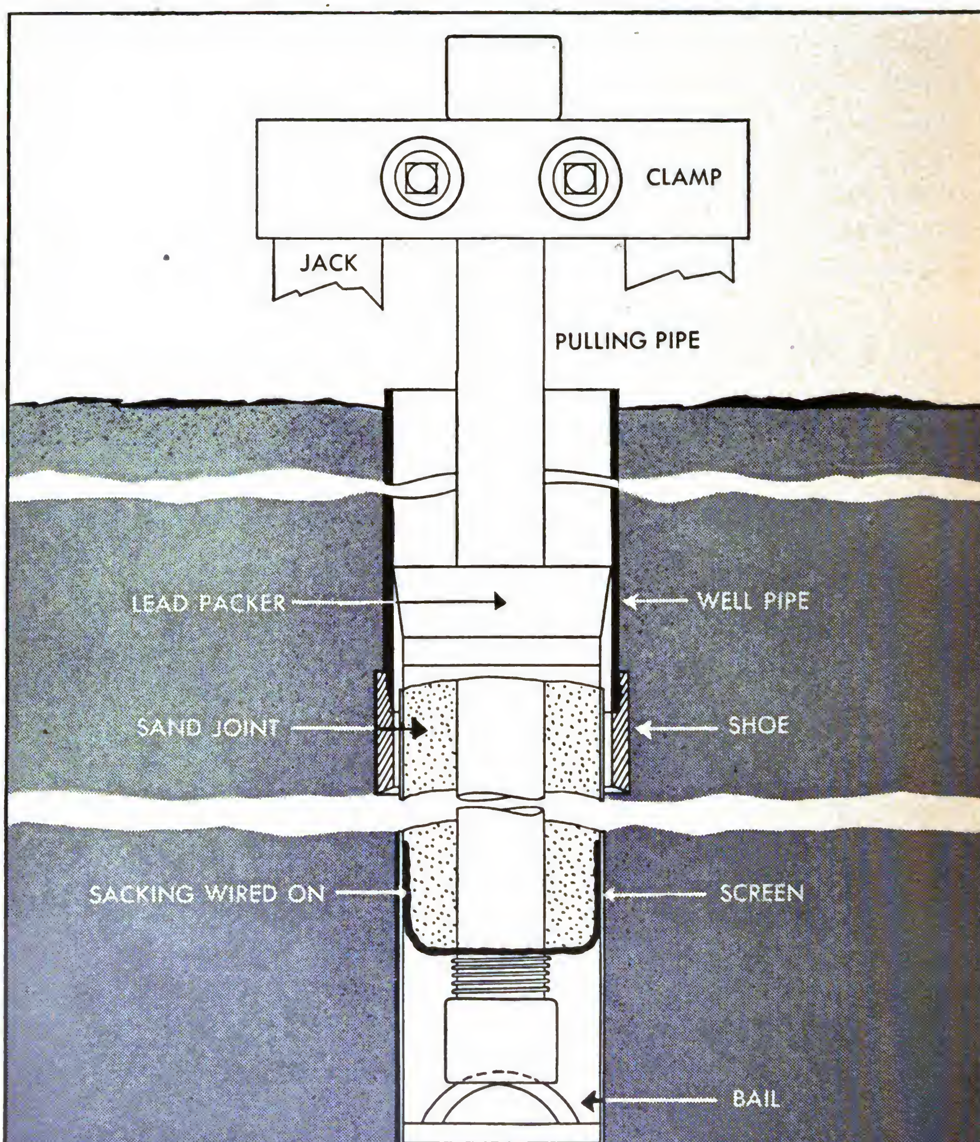


Figure 98. Diagram of sand-joint.

the pulling pipe. It is poured in slowly and evenly all around the pipe. It is well to move the pipe a little at the top while doing this, to be sure the sand does not bridge-over at a joint. A small stream of water can be used to wash down the sand. Enough sand should be poured in to fill the screen about two-thirds or more, but not enough to fill in above

the screen. The proper amount can be calculated in advance by determining the space between the screen wall and the pulling pipe; or a small feeler line of pipe or rods may be used to check the amount of sand in place. If the screen is so long as to contain more than one length of pulling pipe, a line of small pipe or rods is used to tamp the sand to make certain that it does not bridge at the pipe joint and cause a break in the sand joint.

(4) When the sand is in place, tension is slowly applied to the pulling pipe by jacks and clamps or a casing ring and slips. The sand joint thus becomes set and cannot be broken loose without washing out the sand. If it becomes necessary to loosen the joint, it is done by washing out the sand by jetting or with compressed air.

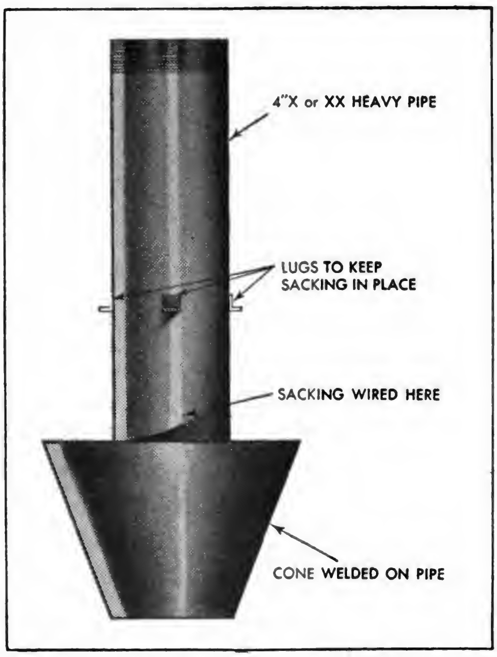


Figure 99. Cone for pulling screens.

(5) It is not good practice to apply pressure rapidly to the pulling pipe. A reasonable pressure is applied and then allowed to set for a short time to give the tension or "stretch" of the pulling pipe a chance to exert a steady pull on the screen. The pressure may be increased gradually, from time to time, until the screen begins to move, after which it may be pulled steadily without difficulty. In this way, there is much less chance of injuring the screen or breaking the pulling pipe than if the pressure were applied rapidly. If heavy pressure is applied quickly, the screen may bulge out or the pulling pipe may break.

(6) After the screen has been started, or after it is out of the water-bearing formation, the jacks usually can be set aside and the screen brought

out much faster with block and tackle. Occasionally the inside of the casing is badly corroded and filled with rust or tubercles, or it may be incrusted; if so it may be necessary to use the jacks even when the screen is up in the casing.

(7) When the screen is on the ground, the sand joint should be washed loose with a stream of water or compressed air.

c. Proper size of pulling pipe. The size of pulling pipe which should be used differs with the size of the well, the pull which may be required, and the preference or convenience of the driller. As an average rule, however, the size of pipe used is about one-half the nominal size of the screen; for example, in pulling an 8-inch screen which has a clear inside opening of 6⅝ inches, a line of 4-inch pipe is used by most drillers. With the smaller and larger screens, smaller pulling pipes are used than this general rule would indicate. Table V gives sizes commonly used.

Table V. Sizes of pulling pipe for various sizes of screen

Size of screen (inches)	Clear opening inside screen (inches)	Size of pulling pipe (inches)	Size of screen (inches)	Clear opening inside screen (inches)	Size of pulling pipe (inches)
3	2	1	5	3⅞	2 or 2½
3½	2⅜	1¼	5⅝	4⅜	2½
4	2⅞	1½	6	4¾	2½ or 3
4½	3⅜	2	8	6⅝	4

d. Type of sand to be used. The type of sand used also varies with the size of the screen and the preference of the driller, as well as with the size of the pulling pipe. The most important thing about the sand is that it must be clean, sharp material of reasonably uniform size. If it is not clean and sharp, the sand joint may not hold tight on a heavy pull. Generally speaking, on all smaller sizes of screens, medium to moderately fine sand is used. On larger sizes, coarser sand may be used; and on the very large sizes where the pulling pipe is considerably smaller than the screen, material as coarse as roofing gravel may be used. To prevent overfilling of the screen, holes can be drilled into the pulling pipe near the upper end of the screen so any excess will run into the pipe.

e. Cone or flange bottom. Figure 99 shows a cone-shaped bottom fitting used instead of a coupling; such a fitting permits a smaller pulling pipe. Some drillers use a flange instead of a cone.

f. Acid treatment before pulling. To avoid the necessity of using extremely high pressures with the resulting risk of breaking the pulling pipe, it is recommended that screens be subjected to a partial

acid treatment before pulling, unless it is known that a very heavy pull will not be required. The screen should be filled with a mixture of about one-half muriatic acid and one-half water, a line of small black pipe being used to convey the acid to its place. Then the acid is allowed to stand for several hours, or overnight if more convenient. Finally the well is bailed or pumped until it is clean of all acid.

127. TESTING YIELD AND DRAW-DOWN.

a. The information to be obtained from a well test is the location of the static water level, the yield, and the depth to water when the well is being pumped at different rates. From these data the draw-down, the yield, and the specific capacity, that is, the yield per foot of draw-down, can be computed. When testing deep wells in which the water-bearing formations are of great thickness or in which the water in the formations is under pressure, it is not necessary to pump the well at its maximum rate to determine its characteristics, because the yield is almost directly proportional to the draw-down. That is, if a draw-down of 5 feet yields 500 gallons per minute, one of 10 feet will yield approximately 1,000 gallons per minute. This statement is not true, in general, for shallow wells, and hence tests of shallow wells preferably should be carried on until the maximum capacity of the well is reached. If the well was developed by pumping, the equipment used for developing it also can be used for testing it; but if other methods were used to develop the well, a pump must be installed to make the tests.

b. Before starting the test on a well it is necessary to measure the depth to the static water level. After this, the well is pumped at the maximum rate long enough for the draw-down and the discharge to become constant. When a condition of equilibrium is reached, the discharge of the pump is measured and the depth to water noted. The difference between this depth and the depth to the static water level is the draw-down. The pumping rate is then reduced until the draw-down is about one-fifth less than it was before. Pumping is continued at this rate until the draw-down becomes constant when the discharge and draw-down are measured again. The discharge is then reduced until the draw-down is two-fifths less than the maximum. This process is repeated until the surface of the water in the well returns to its original level. Under ordinary conditions it is most economical to pump shallow wells at a rate that does not make the draw-down exceed one-half the depth of the water in the well. Deep wells usually are not drawn down to the same extent as shallow ones, but the limitation is not the reduction in discharge per foot of draw-down; it is the increase in the lift which restricts the depth to which the well should be pumped.

Table VI. Discharge over a rectangular weir 12 inches wide

Depth (inches)	Gallons per minute	Depth (inches)	Gallons per minute	Depth (inches)	Gallons per minute
1	36	4 ¾	375	8 ½	900
1 ¼	50	5	405	8 ¾	939
1 ½	66	5 ¼	436	9	978
1 ¾	84	5 ½	468	9 ¼	1, 020
2	102	5 ¾	500	9 ½	1, 062
2 ¼	122	6	533	9 ¾	1, 104
2 ½	143	6 ¼	567	10	1, 147
2 ¾	165	6 ½	601	10 ¼	1, 190
3	188	6 ¾	636	10 ½	1, 234
3 ¼	212	7	672	10 ¾	1, 279
3 ½	237	7 ¼	708	11	1, 323
3 ¾	263	7 ½	745	11 ¼	1, 369
4	290	7 ¾	783	11 ½	1, 414
4 ¼	317	8	821	11 ¾	1, 461
4 ½	346	8 ¼	860	12	1, 508

Table VII. Tabulation of yields in gallons per minute from circular-orifice weirs

Head of water in tube above center of orifice (inches)	4-inch pipe, 2½-inch opening	4-inch pipe, 3-inch opening	6-inch pipe, 3-inch opening	6-inch pipe, 4-inch opening	6-inch pipe, 5-inch opening	8-inch pipe, 4-inch opening	8-inch pipe, 5-inch opening	8-inch pipe, 6-inch opening
	*gpm**	*gpm*	*gpm*	*gpm*	*gpm*	*gpm*	*gpm*	*gpm*
5	56	93	--------	--------	--------	--------	--------	--------
6	62	102	82	155	300	148	240	380
7	66	110	88	168	325	160	260	410
8	70	118	94	180	350	170	280	440
9	75	126	100	190	370	180	295	465
10	80	132	106	200	390	190	310	490
12	87	145	115	220	425	210	340	540
14	94	156	125	238	460	225	370	580
16	100	168	132	253	490	240	390	620
18	106	178	140	268	520	255	415	660
20	112	188	150	283	550	270	440	695
22	118	198	158	298	575	280	460	725
25	125	210	168	318	610	300	490	780
30	138	230	182	350	670	330	540	850
35	150	250	198	375	725	360	580	920
40	160	265	210	400	780	380	620	980
45	170	280	223	425	820	400	660	1, 040
50	180	300	235	450	870	425	700	1, 100
60	195	325	260	490	950	465	760	1, 200

*gpm=gallons per minute.

c. Measuring yield. (1) The measurement of the discharge, when the well is being tested should be made carefully. Either a weir (fig. 100), orifice plate (fig. 101), or other suitable device may be used. Orifice

plates that screw on the end of the discharge pipe of the pump provide one of the simplest means of measuring the discharge from a well. However unless standard plates for which discharge tables have been prepared are used, they should be calibrated by comparison with some standard measuring device.

(2) Where the discharge from the pump is into a pipe line, the devices previously mentioned cannot be used. Under these circumstances, the discharge measurement can be made by installing a thin orifice plate in the line or by timing the flow of color or salt through a known length of the pipe. The thin orifice plate differs from the orifice plate on the end of the discharge pipe in that it is a submerged-flow orifice and requires the measurement of two heads to determine the discharge. It is important

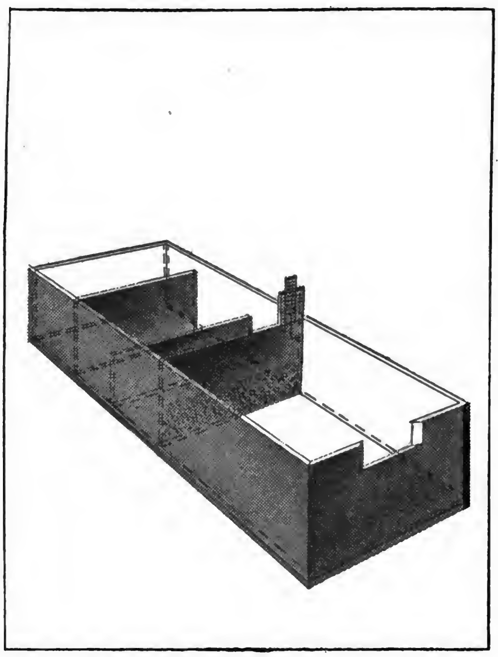


Figure 100. Standard weir.

that these heads be measured at the same points that were used when the orifice was calibrated. When the color or salt-velocity method is used to measure the discharge, the inside diameter of the pipe, as well as the length and the time of transit of the salt or color, must be determined accurately. If there is any deposit or incrustation in the pipe, this method should not be used, for it is impossible to determine accurately the area of the pipe. The pipe used for measuring the velocity should not be less than 100 feet long. Whichever method of measuring the yield from the well is used, it is desirable to make several determinations of each discharge in order to eliminate errors and minimize the effect of minor fluctuations in the flow.

d. Depth to water and draw-down. (1) Chalked tape. The depth to water in most wells can be measured accurately without difficulty, but special equipment must be used to determine the location of the water surface in some wells. A steel tape with a weight to make it hang straight is chalked at the lower end with blue carpenter's chalk and lowered into the well until a foot or two of the chalked lower end is submerged. The proper length to lower may have to be determined by experiment the first time. The wetted length of the tape, which shows up very clearly on the chalked portion of the tape, is subtracted from the total length lowered below the reference point; this gives the depth to water.

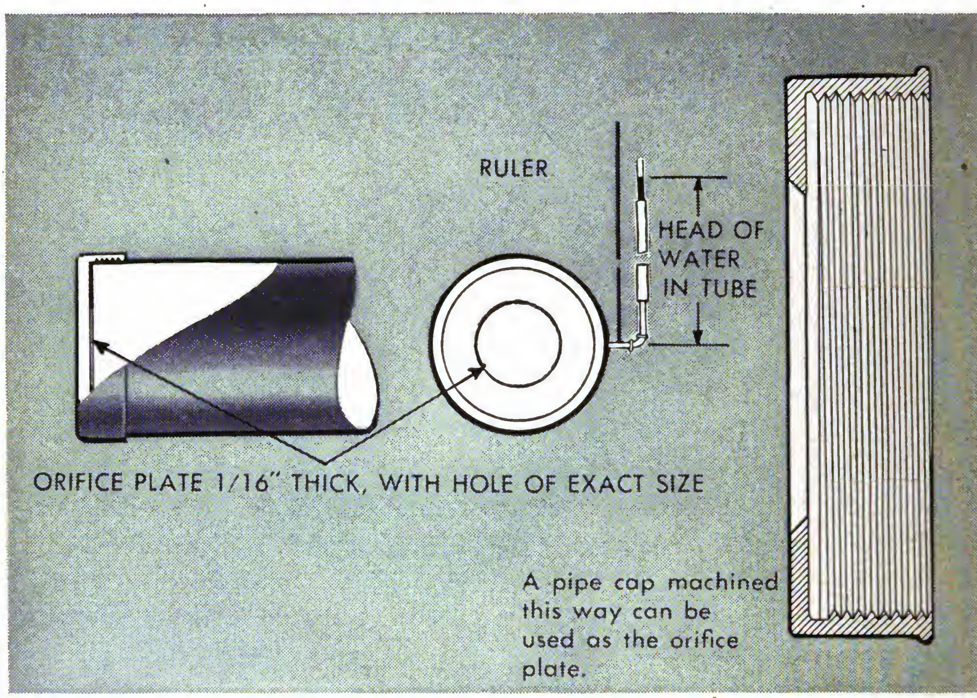


Figure 101. Circular-orifice weir.

(2) Air-line indicator. (a) General. Some deep-well pumps are equipped with pressure gauges and air lines of known lengths. The pressure in feet of water required to force all the water out of the air line subtracted from the length of the air line gives the depth to water. If the gauge is calibrated in pounds, the gauge reading can be converted into pressure in feet of water by multiplying the reading in pounds per square inch by 2.31. If the gauge is calibrated in inches of mercury, the conversion to feet can be made by multiplying by 1.13. The air line should extend about 10 feet below the limit of the draw-down, but it should end within about 5 feet of the suction inlet of the pump.

(b) Instruction for operating air-line indicator. The air line must be airtight in order to obtain correct readings. Air must be pumped into the line until the maximum possible pressure is reached. The bottom of the air line should be about 10 feet above or below the suction of the pump. This is especially true of turbine installations where high velocities will affect the readings. Normally the air line is full of water up to the level of the water in the well (static or pumping level). When air is forced into the line, it creates a pressure which forces the water out of the lower end until it is all expelled and the line is full of air. If more air is then pumped in, air instead of water is expelled, and it is not possible further to increase the pressure. The head of water, "C" or "E" (fig. 102), above the end of the line maintains this pressure, and the gauge shows what the pressure or head above the end of the line actually is. If the gauge is graduated in feet of water (altitude gauge), it registers directly the amount of submergence of the end of the line. This reading subtracted from the length of the line gives the water level (static or pumping level). If the gauge is graduated in pounds per square inch, the reading must be multiplied by 2.31 to give the submergence in feet. Then, as above, the submergence is subtracted from the total length of the line to give the water level.

(3) Electric sounder. Another method of measuring the depth to water in deep wells is to use an electric sounder. There are several types, but the essential feature of all of them is the electric contact made when the sounder strikes the water surface. One of the simplest and best of these devices consists of an insulated wire weighted at the lower end by a flexible lead sheath. The lower end of the wire is bare, but it is shielded from spray or from contact with the casing or the pump column by an insulated sleeve. The other end of the wire is attached to a telephone bell ringer or to a telephone head set and battery. A lead is run from one of the terminals of the battery or bell ringer to the pump column or to the casing. Then when the bare end of the wire strikes the water surface, the circuit is completed; and the ringing of the bell or the click of the head set indicates the sounder has sunk. The depth to water is determined by measuring the length of cable in the well. A two-wire cable with a small electric light bulb in the circuit operated by a storage battery may also be used. This sounder contains a small float that rises and breaks the electric circuit when the sounder sinks into the water. When the light goes out, the sounder has sunk. This device has the advantage that it is possible to tell instantly whether the circuit is in order by noting whether the light is burning.

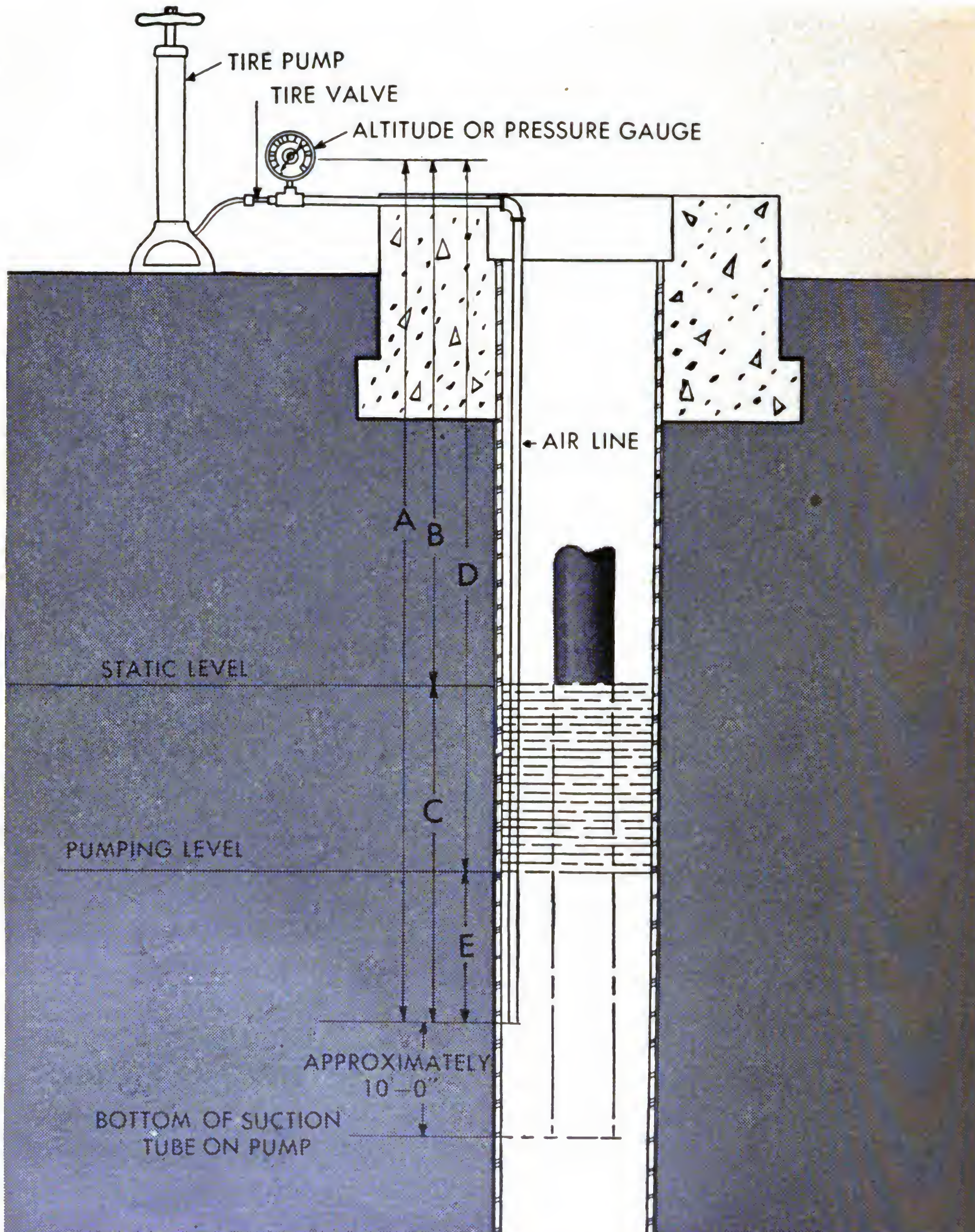


Figure 102. Air-line water-level indicator.

CHAPTER 10

PUMPS

SECTION I

INTRODUCTION

128. SHALLOW AND DEEP SOURCES OF WATER. For purposes of determining pumping requirements the sources of water are divided into two classes, shallow sources where the total suction lift never is more than 22 to 25 feet, and deep sources where the pumping lift is greater than 25 feet. Shallow sources include ponds, lakes, springs, rivers, cisterns, and any wells in which the water stands within 22 to 25 feet of the surface when pumping. Deep sources are chiefly drilled wells, in which the water surface stands 25 feet to several hundred feet below the surface when pumping. Some dug, bored, or driven wells have water levels below the vertical 25-foot level.

129. SELECTION OF EQUIPMENT. The distinction between shallow and deep wells is important, and the proper equipment for each well is carefully selected. For example, the static level in a well which originally required a shallow type pump may be lowered by heavy pumping, or drought conditions, and require a complete change of pumping equipment.

SECTION II

SHALLOW-WELL PUMPS

130. PITCHER PUMPS.

a. Most pumps of the pitcher-spout type (fig. 103) have a tilting check valve, which makes them easy to drain. By elevating the pump handle to its highest point, the plunger is forced down on the check valve causing it to open, drain the pump, and release the water in the suction line. It is simple to reprime such pumps. Although the use of a foot valve on pumps of this type may be held to hold prime, such a valve prevents convenient drainage. Foot valves, therefore, are not installed where either the pump or the suction line is exposed to freezing temperatures.

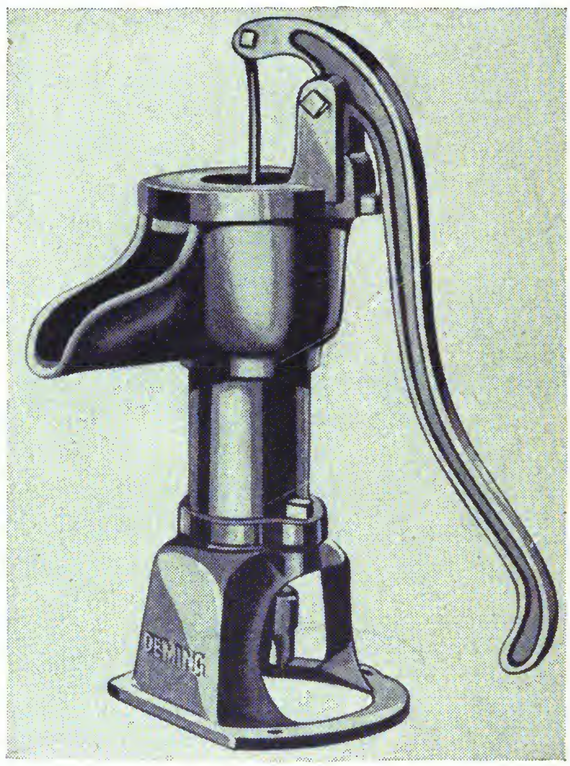


Figure 103. Pitcher pump.

b. Renewal of plunger and check-valve leathers in pumps of this type is about all the servicing required. Such renewals are simple.

c. All pumps in this group depend upon atmospheric pressure to force water from the source of supply to the pump. The atmospheric pressure at sea level is equivalent to a lift of about a 34-foot column of water. A well-constructed pump in good condition may develop a lift of 28 feet or more, but allowance must be made for elevation above sea level, friction, presence of air in the water, and eventual wear. Therefore, when the vertical suction lift plus friction loss exceeds 22 feet of water for plunger type pumps and 15 feet for centrifugal pumps, reduced capacity and more frequent failure may be expected. The likelihood of complete failure is

less when the pump is operating against pressure on the discharge side and is equipped with a good foot valve on the suction line. Suction-pipe threads, including the connection to the pump, should be carefully sealed with pipe-thread compound and securely tightened. There must be no leaks in the pipe. Drain plugs, caps, and gaskets in the pump must be tight. The suction line should never be smaller than the pump's suction tapping.

d. The flow of water to the pump sometimes is retarded by clogging of the suction line or strainer. Strainers of fine mesh sooner or later become coated with sediment. A strainer if used on the pump end of the suction line may eventually clog with sand or gravel. Noisy operation sometimes develops when the suction lift is too great or the suction line too small or otherwise restricted. This is particularly true of plunger-type pumps. When a hand pump is used under these conditions the handle is likely to fly up when released during the downstroke. In most wells, minute quantities of air or other gases are present in the water and are released during pumping. Unless the suction line is properly laid this air eventually may become entrapped in sufficient quantities to retard or prevent operation.

e. Pitcher pumps are useful for developing drive-point wells. Other types of hand pumps also can be installed on shallow wells when only a small quantity of water is needed. For wells in continuous use power pumps are used.

131. TURBINE PUMPS, SHALLOW-WELL TYPE.

a. The principle parts of the pump are the casing (A), impeller (B), pump shaft (C), and packing glands (D). One of the principle features is simplicity of construction (see fig. 104).

b. The impeller is a disk mounted on the pump shaft, by which it is driven. This disk has numerous small vanes or blades on one or both sides, starting from the outer edge and extending part way to the center. Rotation of the impeller in a closed channel formed by the casing or casing liners forces the water from the inlet side of the pump to the discharge side, which is adjacent and separated by a close-fitting block or partition.

c. Clearance between the impeller and the adjacent surface of the casing or casing liners, eliminates metal-to-metal contact. Liquid is carried in the channel on both sides of the impeller, and the developed pressure is equally distributed, with no end thrust.

132. ROTARY PUMP. A typical rotary-gear pump (fig. 105) consists of only two moving parts—the pumping gears.

a. These gears rotate in an accurately fitted case. Close tolerances

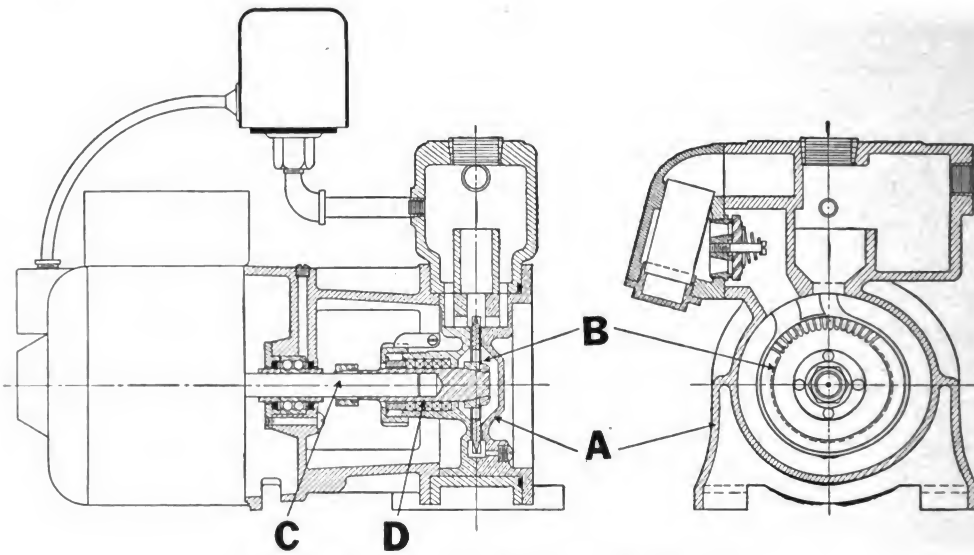


Figure 104. Turbine pump with circular case.

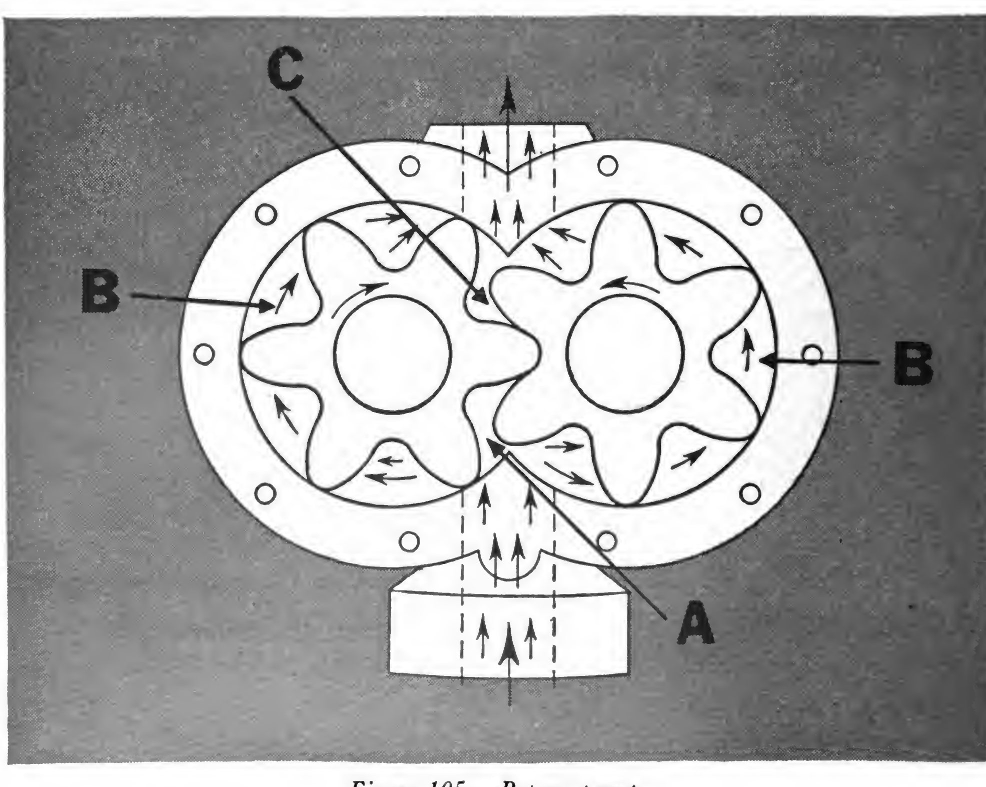


Figure 105. Rotary pump.

increase efficiency and reduce power requirements. The teeth of the pumping gears moving away from each other pass the inlet port at point *A* and produce a partial vacuum, expelling the air from the suction line. This causes the water to rise in the suction pipe and into the pump, where it is carried between the teeth of the pumping gears around both sides of the pump case at points *B*. The action of the teeth meshing at point *C* results in a condition similar to that set up by a valve, forming a seal that forces the water into the discharge line.

b. In a rotary gear pump, the flow of water is continuous and steady without pulsations. The quantity of liquid pumped per hour is determined by the size of the pump and the speed at which the pump shaft rotates.

c. All internal parts, including the bearings, are lubricated by the flow of water. The rotary gear pump is suitable for 22 to 25 feet of suction, and will deliver any pressure the equipment can stand.

133. CENTRIFUGAL PUMPS.

a. A centrifugal pump is one in which the water is drawn into the pump from the suction pipe at the center or eye of an impeller which, when rotated in a casing, throws the water by centrifugal force outward from the center to the discharge.

b. A centrifugal pump and its suction pipe, which is provided with a foot valve, must be completely filled with water before starting. As soon as the impeller starts rotating, the water is thrown outward from the center by centrifugal force. This forces the water already in the casing out through the discharge pipe.

c. The water moving out of the impeller tends to produce a vacuum in the center. Atmospheric pressure, acting upon the surface of the water source, immediately forces more water up the suction pipe and into the impeller to replace what has been expelled. This action is steady and continuous. The action of the water in the impeller is similar to that of the plunger of a reciprocating pump in producing a suction lift.

d. If the head against which the water must be pumped is increased, the speed remaining constant, the quantity discharged will decrease, and vice versa. If the head is increased beyond the head capacity of the pump (shut-off head) no water will be pumped.

e. The essential parts are a rotating member usually called impeller *A* and a stationary casing *B* surrounding it (fig. 106). The impeller has a number of backward-bent blades fastened to a hub or disk mounted on the shaft. The casing, which has a volute or snail-like passage, extends around the periphery of the impeller and gradually increases in

cross sectional area from a point near the nozzle or pump outlet to the outlet itself.

f. The pressure that a centrifugal pump develops depends almost entirely on the diameter of the impeller and the speed, whereas its capacity depends more on the width of the impeller and the proportions of the water passages.

g. If two centrifugal pumps are connected in series, that is, with the discharge of the first connected to the suction of the second, the pump capacity is that of the first pump but the head is the sum of the discharge heads of both pumps. The same effect is obtained by placing two or more impellers in one casing (multi-stage pump). If the two pumps are

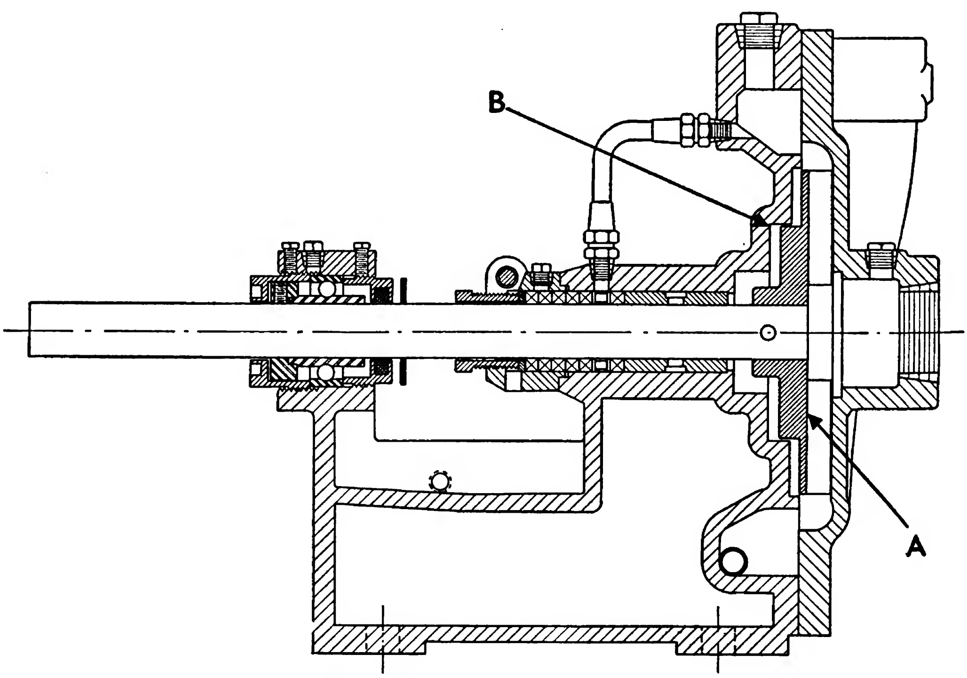


Figure 106. Centrifugal pump.

connected in parallel, that is, if both suctions are connected to the source and both discharges connected to the discharge line, the head is the same as that of the individual pumps, but the capacity is the sum of the capacities of the two pumps.

134. SELF-PRIMING PUMPS, CENTRIFUGAL.

a. General. The centrifugal pumps issued for general use, and which are used for utility service with well-drilling equipment, are of the self-priming type; that is, they contain a priming chamber which, when filled, makes repriming unnecessary until the priming chamber has been drained. On pumps that are not self-priming it is necessary to

provide a foot valve on the suction line, which closes when the pump is stopped, thus keeping the suction line filled with water.

(1) A pump does not "lift" water in the same way it forces water or creates a pressure. Actually the pump exhausts the air from the suction line, thus creating a partial vacuum or lowering the pressure to a point below that of the atmosphere. The only force available to "lift" water to a pump is the pressure of the atmosphere, which at sea level is only 14.7 pounds per square inch, or the equivalent of 34 feet of water. A nearly perfect vacuum is difficult to obtain, even in a laboratory, and in practice suction lifts are considerably less than the theoretical 34 feet.

(2) At 5,000 feet above sea level, the maximum practical suction is reduced to 20 feet. Any well-designed, self-priming pump will develop a vacuum greater than required for a suction lift of 25 feet, but the great decrease in the amount of water pumped, the difficulty of maintaining correct conditions, and avoiding air leaks makes such suction lifts impractical.

b. 55 gpm self-priming pump sets. (1) Description. The 55 gpm pumping set (fig. 107) consists of a self-priming centrifugal pump mounted on a common base with and driven by a single-cylinder, four-cycle, air-cooled gasoline engine. The unit is close-coupled, and the impeller in the pump is attached directly to the end of the engine crankshaft. A self-adjusting mechanical seal prevents leakage of water between the pump and the engine. The only adjustment required on this seal is an occasional partial turn on the grease-cup nut. This type of pump is designed for operation at approximately 15-foot suction lifts, and gives its best performance at about that point. It will lift water from greater suction lifts, but the capacity and efficiency of the unit fall off rapidly at greater lifts. Furthermore, as the head or discharge pressure is increased the capacity falls, until the discharge is stopped completely. Conversely, as the discharge pressure or head is decreased, the capacity increases.

(2) Installation. Install the pump as close to the source of water supply as possible, to eliminate excess suction lifts. Install full-size suction piping with as few elbows or bends as possible to cut down pipe friction. Suction piping must slope continuously upward from the source of water supply to the pump, to eliminate air pockets. Be sure there are no leaky joints in the suction pipe. Use pipe cement on all joints. If suction hose is used, make certain it is airtight throughout its length. If the suction or discharge piping or hose are to be removed frequently, the connections should be made through unions, so that the pump housing will not become worn.

(3) Priming the pump. To prime the pump, remove the priming plug beside the discharge tapping and pour water in the pump case until

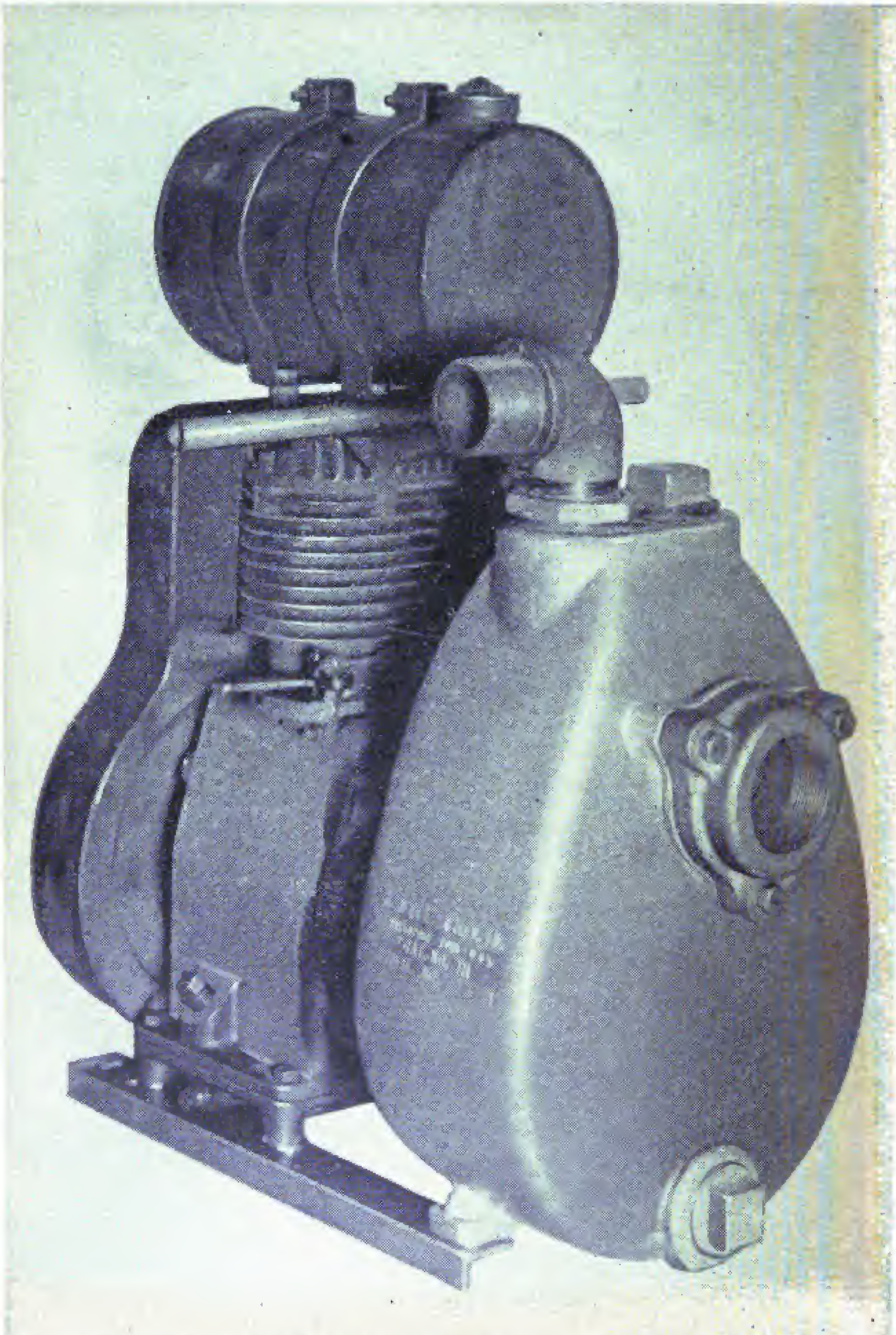


Figure 107. Standard 55-gallon-per-minute centrifugal pump.

the case is *full to the very top*. Failure to fill the priming chamber to the top causes the pump to prime more slowly than it should. If the pump takes longer than 5 minutes to prime there is something mechanically wrong, and the operator should refer to **(6)** below. This pump automatically attains its prime from 15-foot suction lifts in 2 minutes or less, depending on the length and size of suction pipe. If a valve is used in the discharge line it should be wide open during priming. For starting instructions, refer to the instruction plate attached to the engine, and to the operation manual for the engine.

(4) Operation. (a) If a valve is used in the discharge pipe do not shut it off completely for long periods. When it is shut off, the water simply circulates inside the pump housing and eventually becomes quite warm. If allowed to get too hot, it damages the seal. No harm is done as long as the housing or case of the pump does not get too warm for the operator to hold his hand on.

(b) If muddy or sandy water is being pumped, drain the pump before shutting down after a period of use, such as at the end of the day. This prevents sediment or sand from settling inside the pump case and plugging up the priming hole. Should the priming hole become plugged, clean it out by removing the drain plug at the bottom of the pump. This operation makes it possible to clean out the pump.

(c) In freezing temperatures, never let the pump stand idle full of water long enough to freeze and burst the pump housing. If the pump must stand idle during cold weather, remove the plug from the bottom of the housing, allowing the entire pump to drain.

(d) If water is seen to drop from around the seal between the pump and the engine, repair the leak at once, as continued operation may ruin the grease retainer and allow water to enter the crankcase of the engine, thus emulsifying the crankcase oil and damaging the engine bearings.

(e) If absolutely necessary to operate the pump with a leaky seal, watch carefully the cylinder oil in the engine and drain it frequently. Carelessness in this regard may cause a bearing to burn out through faulty lubrication.

(f) Should the engine develop a loose main bearing, repair it at once, because it may cause failure of the grease retainer and the seal as well as excessive wear on the impeller.

(g) Should the impeller become unbalanced, due to excessive wear caused by pumping sandy water, probably the pump and engine will vibrate excessively. Continued unbalance eventually will cause the crank shaft to break.

(5) Lubrication. The only lubrication required for the pump itself

is that required by the seal. The grease cup on the seal should be filled with a good, soft grade of lime-base, waterproof grease. Do not use common soda soap grease, as this is soluble in water.

(6) Possible causes of trouble. If the pump fails to prime look for—

(a) Plugged priming hole (clean out through drain plug).
(b) Air leak in suction pipe or hose, or leaky seal.
(c) Collapse of lining of suction hose.
(d) Plugged end of suction pipe or suction strainer.
(e) Lack of water in housing of pump.
(f) Clogged, worn out, or broken impeller.

SECTION III

DEEP-WELL PUMPS

135. PLUNGER TYPE. The most common type of deep-well pump is the plunger type which consists of a belt- or gear-driven pumping or working head, located usually at the surface of the ground, and a cylinder or working barrel, located usually below the lowest water level of the well. In operation, a pulley drives a pinion shaft and, through suitable gearing and a cross head which guides the motion, the plunger rod is made to work up and down in the well. The gear case, which carries the working-head mechanism, contains a supply of oil for lubricating the mechanical parts.

a. Principle of operation. (1) The steel or wood pump rod is installed in the well in sections of convenient length, with suitable couplings.

(2) The working barrel may be single- or double-acting. In the single-acting type, there is a check valve at the bottom of the cylinder and a similar valve in the plunger. The water flows into the working barrel through the check valve while the plunger is making its upstroke. On the downstroke, this water is held in the working barrel by the foot valve, and the plunger descends to the bottom of the working barrel while the water passes through the valve in the plunger. On the next upstroke, the valve in the plunger closes and the water above it is raised up into the drop pipe. At the same time the foot valve opens and the cylinder fills with water again. With each upstroke of the pump, the plunger

forces a cylinder full of water into the drop pipe and thence out to the discharge tank. Double-acting cylinders are designed so water is discharged on each downstroke as well as on each upstroke of the working head, making it possible to obtain a flow about 60 percent greater than from the single-acting working barrel.

(3) The theoretical capacity of the pump depends on the displacement of the working barrel and the number of strokes per minute, or speed, of the pump. The actual capacity is somewhat less, depending on leakage losses.

b. Installation of plunger-type deep well pumps. This type of pump must be installed directly over the well, the drop pipe and pump rod extending down to the cylinder or working barrel. The self-oiling pump shown in figure 108, equipped with a one-horsepower gasoline engine, has been procured for Army use. The pump has a 6-inch stroke, a 2½-inch working barrel, and a capacity of about 6 gallons a minute. A pump similar but slightly larger is equipped with a larger engine, and has a 3¼-inch or 3½-inch working barrel. With a 6-inch stroke the pump has a capacity of about 10 to 12 gallons a minute. The handle can be replaced with a walking-beam type of handle so the pump can be operated by four men.

(1) Selection of cylinder and other well equipment. (a) The most important part of a plunger type deep well installation is the equipment in the well. The function of the pump head is to operate the plunger in the cylinder in an up-and-down movement. If proper attention has not been given to the installation of the cylinder the pump may operate hour after hour without discharging water. At different times the terms "cylinder" and "working barrel" have been used. Some manufacturers use the term working barrel to describe open-top cylinders.

(b) The open-top cylinder (fig. 109) is recommended where it can be used. The inside diameter of the drop pipe is slightly larger than the inside diameter of the cylinder. This permits lowering or removal of the plunger and check valve through the drop pipe. For example, a 2¼-inch, open-top cylinder requires a 2½-inch drop pipe, and the valves for a 2¼-inch cylinder can be pulled through the 2½-inch pipe.

(c) After installation has been completed the drop pipe remains permanently in the well. When necessary to repair the cylinder, for example, by replacing the cup leathers on the plunger and check valve, or the valve facings, the pump rod with the plunger and check valve is pulled upward through the drop pipe. The installation of the single-acting and double-acting open-top cylinders are discussed below.

(d) Some open-top cylinders can be screwed to the bottom of the well

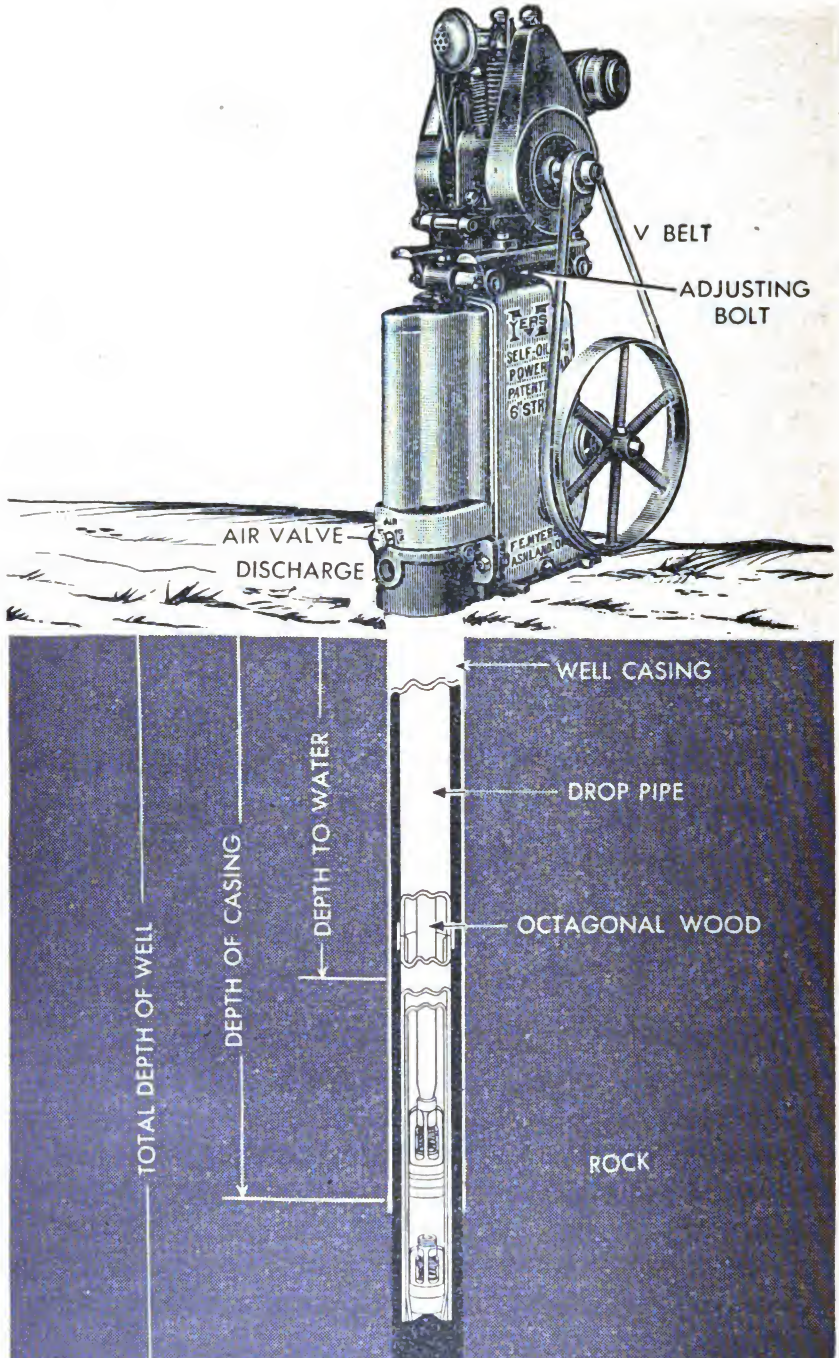


Figure 108. One-horsepower, self-oiling, engine-driven, plunger pump, used by the Army.

casing and lowered into the well. Separate drop pipe is not needed, the casing serving as the conductor pipe.

(e) Closed-top cylinders (fig. 108) are recommended where economy in the initial installation is desired and where the casing size is too small for an open-top cylinder of the capacity desired. They are also used for wells where only two or three lengths of drop pipe are necessary and could easily be pulled by hand.

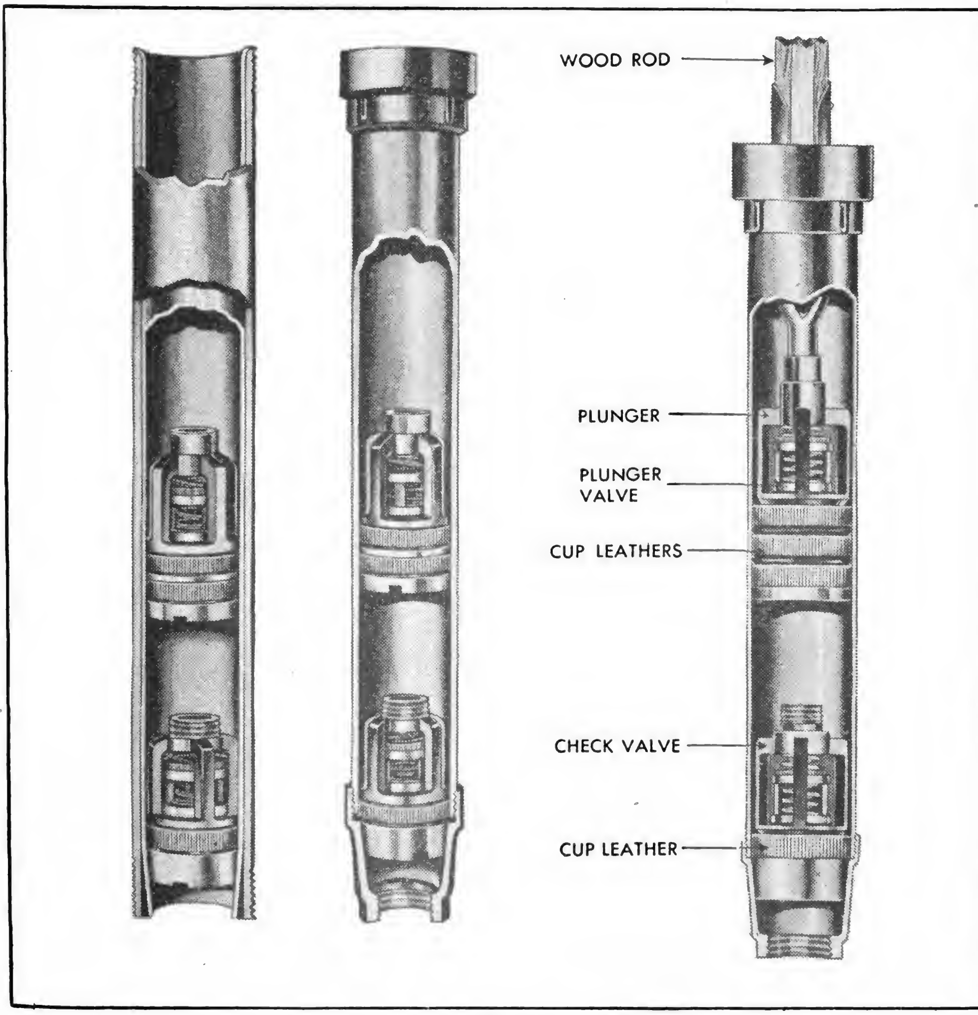


Figure 109. Open-top well cylinder.

(2) Open-top cylinder. The following procedure is recommended for installation of single-acting, open-top cylinders:

(a) Prepare the drop pipe beforehand, by reaming out the ends and fitting one end of each length with a coupling. Inspect the pipe carefully for blisters or other flaws. The coupling will serve as a stop for the pipe clamp as the pipe is being lowered.

(b) Now remove the plunger and check valve from the open-top cylinder and examine them carefully. Be sure the valves are working freely. Attach the shell only to the drop pipe and lower it into the well. Hold the first length of pipe with a pipe clamp while the second length is raised with the hoist and screwed into the coupling on the first length. Attach additional lengths of pipe until the working barrel reaches below the pumping-water level. The discharge casting or pipe head can be removed from the main body of the pump and threaded tightly onto the top length of pipe before this length is attached to the rest of the pipe in the well. The discharge casting prevents the pipe from slipping through the clamp.

(c) There are several methods by which the plunger and check valve are placed in the well.

1. When the check valve and plunger are installed separately, first thread the check valve lightly onto the sucker rod and lower it until the valve is seated in the lower cap of the open-top cylinder. Tap the upper end of the rod with a wooden mallet or a piece of timber to seat the valve firmly. Unscrew the rod and remove it from the well. Next attach the plunger to the rod and lower it into the well. The plunger and each joint of rod are threaded on securely.

2. Another method sometimes employed to install check valve and plunger is to fasten the two together and lower them at the same time. After the check valve is seated in the lower cap, tap the rod with a piece of timber and disconnect the plunger. This speeds up the installation, but there are several serious objections to it. One is the possibility of the plunger unscrewing from the rod, or of one of the rod couplings being disconnected. Still another is the possibility that the plunger and check valve will not be disconnected so they will operate together when the pump is started.

3. Another method is to seat the check valve before lowering the shell. The objection to this is that pipe cuttings, stones, sticks, and other objects may drop into the well, lodge in the check valve, and hold it open. Discovered after the pump has been started, it is necessary to pull the check valve.

(3) Sucker rod. (a) Octagonal, wood sucker rod (fig. 110) often is used for open-top, single-acting, working barrel installations. Wood is preferable because it is buoyant in the water and because it does not tend to crystallize and break at the couplings as does steel rod.

(b) The pump rod is cut to the proper length so the plunger will not strike at the bottom of the stroke, or will not lift too high on the upstroke.

The following procedure is suggested, although many other methods are as good:

1. Before unbolting the discharge casting from the gear case of the pump, turn the pump by hand to the extreme end of the downward stroke. First, measure the distance from the top of the pipe thread in the discharge casting to the top of the box and pin thread on the piston rod; second, measure the distance from the top of the thread on the piston rod to the top of the opening between the forks of the wood-rod coupling; and third, allow for clearance between the plunger and check valve of the working barrel. The allowance for clearance should be one-half the total clearance in the cylinder. Add these three measurements together to get the length which should be cut off of the rod.

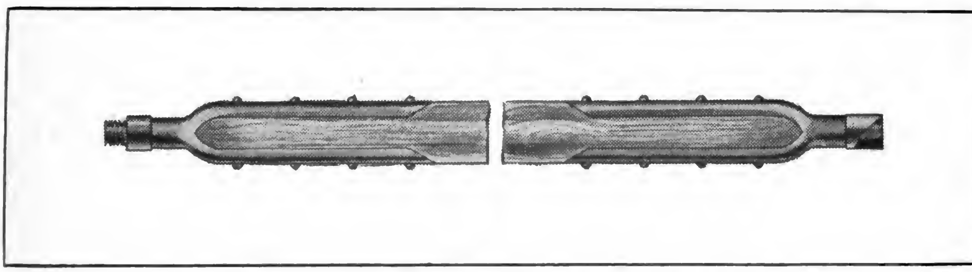


Figure 110. Octagon wood rod with couplings.

2. With the sucker rod down as far as it will go, mark the rod at the top of the thread in the discharge casting, pull up the rod and mark off a distance equal to the sum of the three measurements, and then cut off the rod and shape to fit the forks of the wood-rod coupling. The above instructions refer particularly to octagonal and rectangular wood rod.

(c) Where *steel rod* or pipe is used for sucker rod the first and second measurements are taken as for wood rod. The third measurement is about half the length of the coupling on the upper end of the steel or pipe sucker rod.

(d) The pumps (fig. 108) are equipped with octagon wood rods cut to proper length. Long pump cylinders are furnished to allow for some adjustment.

(4) To install a closed-top cylinder (fig. 111) a slightly different procedure is followed. The complete cylinder with the valves inside is attached to the drop pipe and sucker rod. Start by slipping a length of rod inside a length of pipe then connecting the rod tightly to the coupling on the plunger stem. Thread the pipe tightly into the upper cap of the

cylinder. Lower the cylinder with the first length of pipe into the well. Attach each succeeding length in the same manner until the cylinder is below the water level. Solid steel sucker rod is used in most closed-type installations. Pipe sucker rod also can be used if not too large to obstruct the flow of water in the drop pipe. Octagonal wood rod also is commonly used.

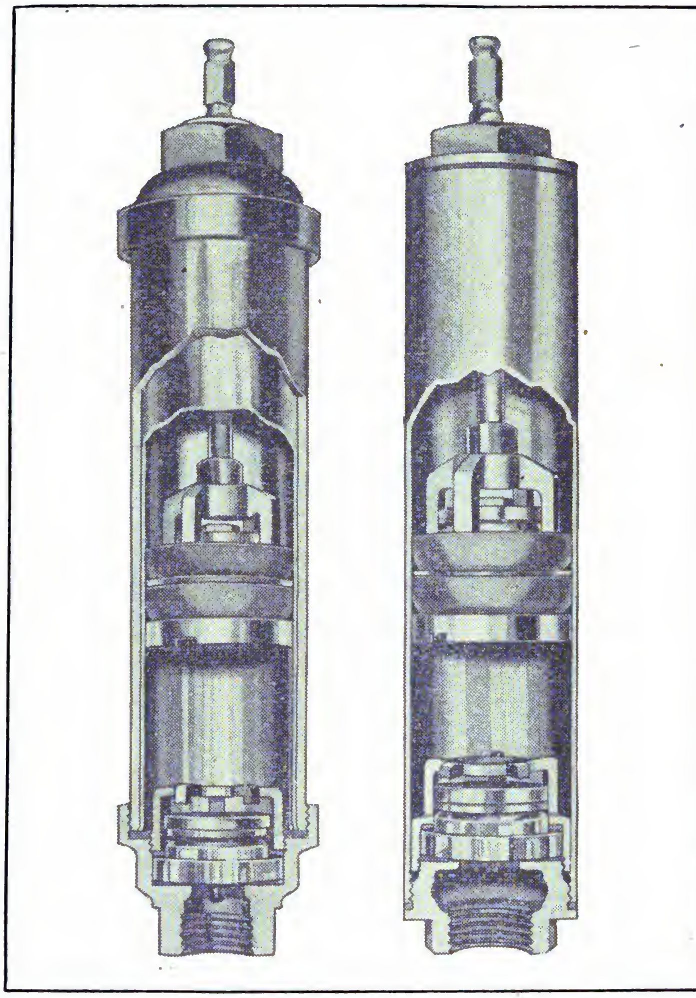


Figure 111. Closed-top well cylinders.

c. Starting pump for the first time. (1) Fill gear case with a good grade of light (SAE 20) oil, up to the oil level line marked on the gear case.

(2) Oil the motor, using light oil as instructed on the tag attached to the motor.

(3) Be sure the setscrews on the pump and motor pulleys are securely tightened after checking alignment of the drive.

(4) If the shutoff valve is used between pump and tank, be sure it is open.

(5) *Turn the pump pulley by hand* to make sure the pump works freely and that the plunger in the cylinder or working barrel clears properly at both ends of the stroke.

(6) A few drops of neat's-foot oil, melted tallow, or even lard, in the air cylinder of the plunger tube of the water piston will keep the plunger leathers in good working condition.

(7) The pump pulley must run in the direction indicated by the arrow on the side of the pump.

136. DEEP-WELL TURBINES.

a. Construction and operation. A deep-well turbine pump has a vertical motor located at ground level, driving a vertical shaft extending down into the well below the pumping level. This shaft drives one or more impellers that operate on the same principle as the centrifugal pump described previously. Water flows into the bottom of the housing that surrounds the impeller. The rotating impeller creates pressure which forces the water outward and then upward through the pipe to the surface. The pressure developed depends on the speed and diameter of the impeller. These are both somewhat limited and, in most wells, the pressure developed by one impeller is not sufficient to lift the water to the surface and put it into the tank under pressure. Additional impellers may be added to provide sufficient pressure to raise water from any desired depth. Each impeller with its housing is called a stage, and pumps built up with several impellers one above another are called "multi-stage" pumps. The use of turbine pumps is confined almost exclusively to wells 4 inches in diameter or larger. Initial velocity is not increased, though repeated velocities become cumulative, increased pressures.

b. Model 6–M turbine. Various turbine pumps used by the Army are all essentially the same. The Peerless 6–M turbine pump (fig. 112) described below, is typical. Designed for wells of at least 6 inches inside diameter, this pump supplies 200 gallons of water per minute with the pump bowls set at 150 feet, and will operate against a 200-foot head. The pump is designed to work at 1,800 rpm. For wells in which the water level is more than 150 feet from the surface the Hi-Lift pump described in paragraph 137 is used.

(1) Discharge head assembly. The discharge head (fig. 113) is an iron casting supporting the bowl unit and column in the well. It also supports the gear drive above ground and furnishes a means for connecting the column pipe to the discharge piping. The discharge head incorporates an efficient type of packing gland, which prevents water leakage around the drive shaft. The discharge casting has connection for manual prelubrication.

(2) Gearturbo drive. The Gearturbo drive head (fig. 115) is a right-angle gear used for coupling the vertical pump shaft to the horizontal driver. Heat-treated, hardened, and ground nickel-alloy spiral-bevel gears, lapped for specific operating tooth velocities, are used in the head. Both vertical and horizontal shafts are supported on double-tow precision ball bearings to prevent damage to gear teeth from upthrust

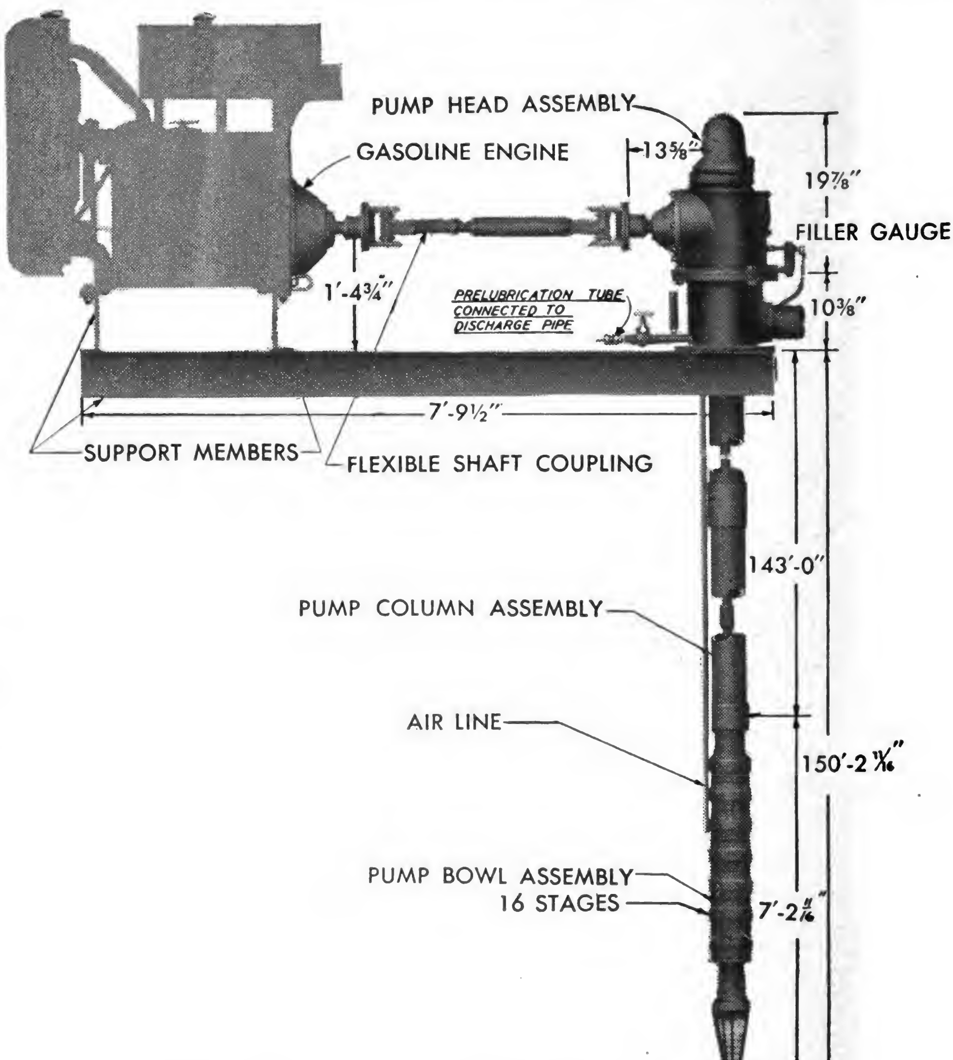


Figure 112. General assembly of 6–M deep-well turbine pump.

of the pump shaft on starting. An annealed, semisteel, one-piece main body casting insures permanently correct gear mesh. Lubrication is by a centrifugal type oil pressure pump that constantly circulates cooled oil to the gears and the bearings. The pump shaft is protected against engine reversal by an antireverse ratchet. The gear head is designed for long and continuous full-load duty.

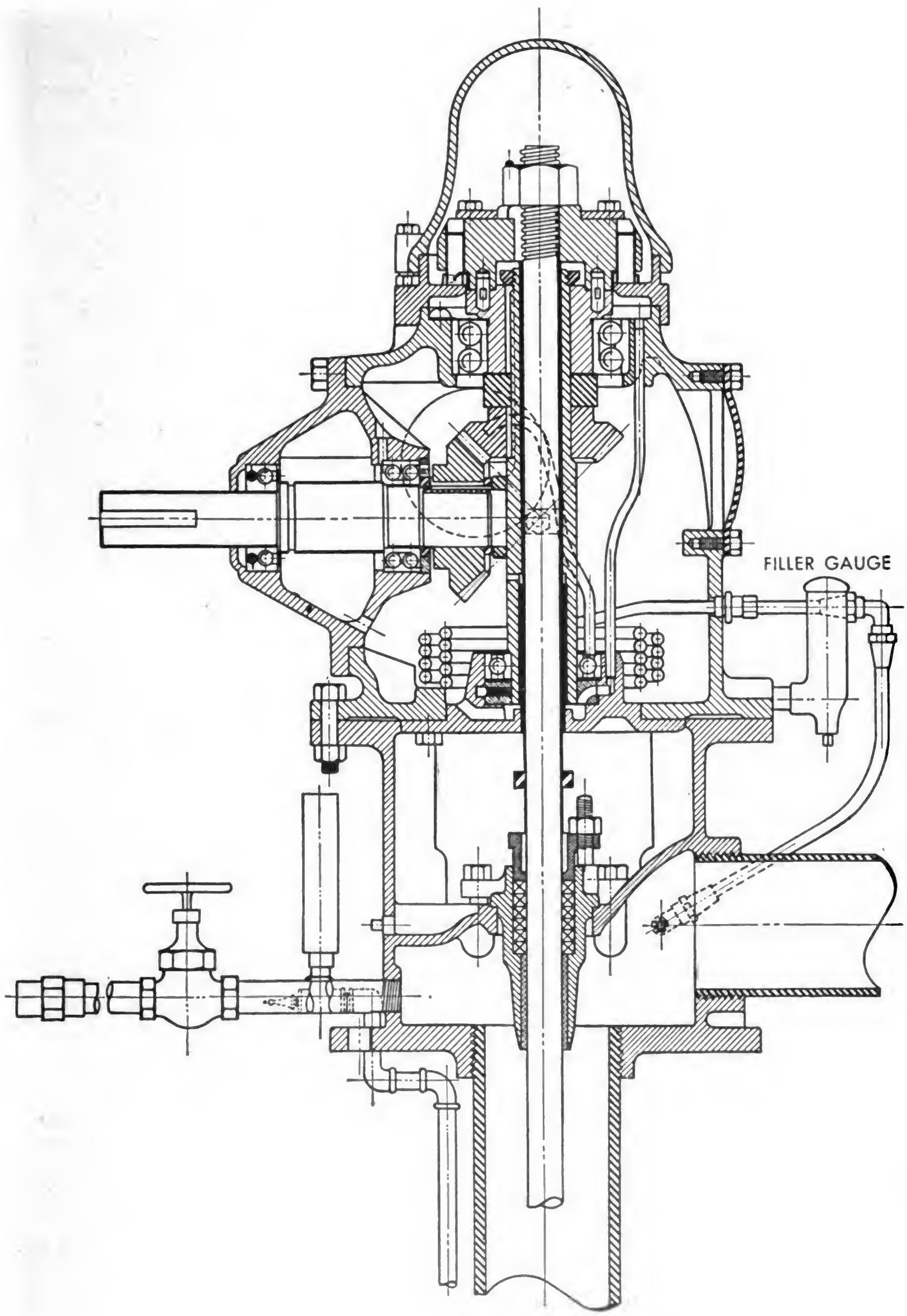


Figure 113. Discharge head of turbine pump.

(3) Column pipe line shaft and bearings. **(a)** The column is a 4-inch standard black steel pipe with a taper thread so a double joint is provided. When the column pipe ends butt against the spider ring, the threads also are tight.

(b) The line shafting is a heavy turned, ground, and polished precision steel rod, 1 inch in diameter. The shafting is accurately threaded and faced, and the central portion of each end is counterbored so, when the shaft ends butt in the center of the coupling, they remain true and

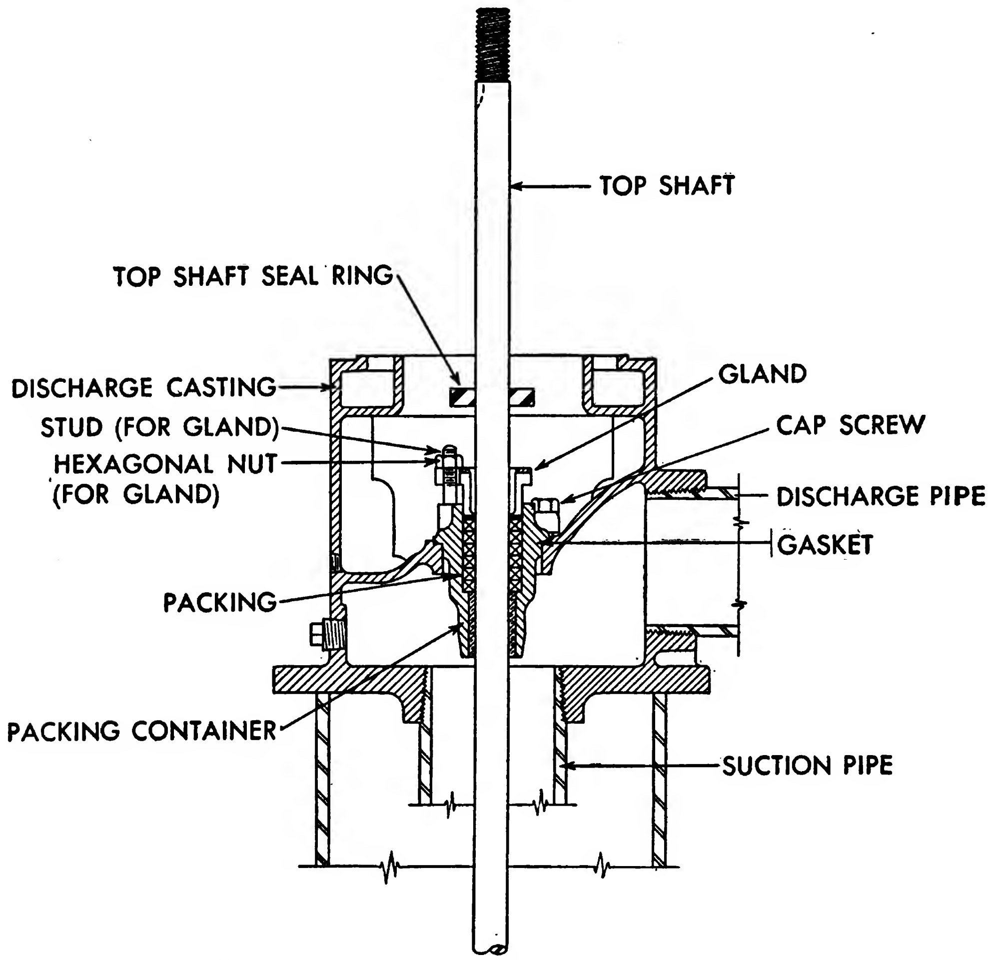


Figure 114. Discharge casting for Hi-Lift and turbine pumps.

concentric. The shaft couplings are machined from solid stock for added strength and accuracy. An air-relief hole in the center of the coupling allows escape of air when butting two shaft ends in the center.

(c) The shaft bearings are cutless fluted rubber, mounted in bronze spiders held in place between the ends of lengths of column pipe at each joint. The first bearing is 3 feet below the pump head. Bearings are spaced at 10-foot intervals along the column except immediately above

the bowls, where there are bearings 5 and 10 feet above the top of the bowl. Close operating clearance is maintained between the shaft and rubber bearings, and the bearings are rigidly fixed in the bronze spider to eliminate gyration and vibration (fig. 116).

(4) Pump bowls. The pump bowls of close-grained cast iron, which actually lift the water (fig. 117) are at the bottom of the column. The one-piece, bronze, fully-inclosed impellers, when used in conjunction with

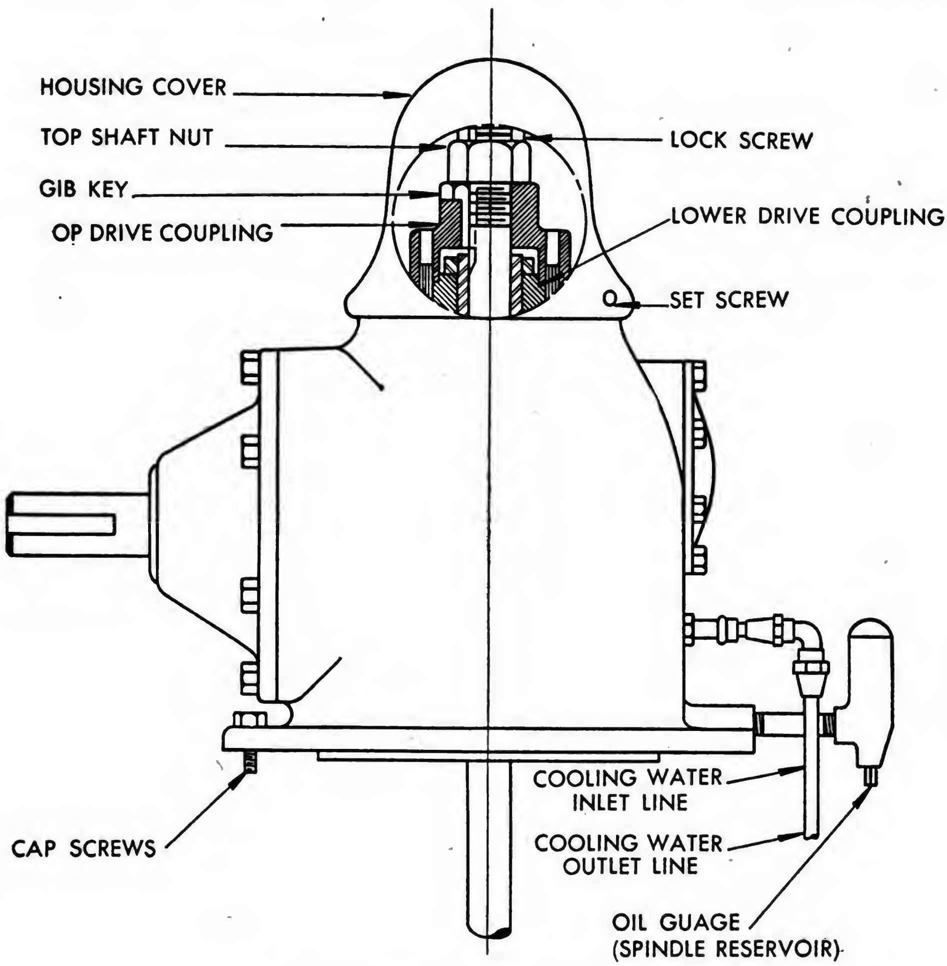


Figure 115. Gearturbo pump head.

Peerless resilient double seal rings, allow compensation for wear by endwise adjustment. The pump-bowl shaft is of turned, round, and polished precision stainless steel. A special tapered steel lock fits the impeller to the shaft to avoid the necessity of key-seating the impeller shaft, thus guaranteeing accurate register of each impeller with its individual bowl case and providing a full-strength shaft throughout the entire pumping element. Long, closely spaced rubber and bronze bowl bushings and

bottom manifold bushings furnish maximum bearing support for the impeller shaft. The strainer, located below the suction manifold, is manufactured by winding a heavy, galvanized, half-round rod around a rigid steel frame to which a pipe coupling of the proper size is attached at the upper end.

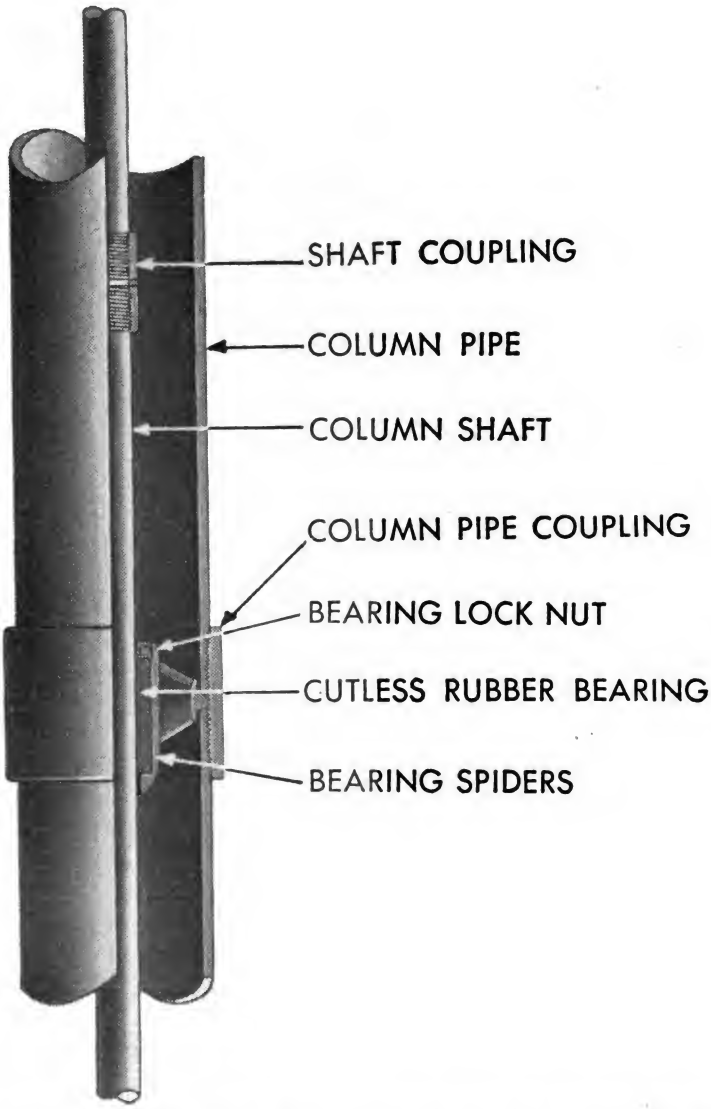


Figure 116. Pump column with open line shaft as used with the Hi-Lift and turbine pumps.

(5) Flexible shaft. The Watson-Spicer needle-bearing flexible shaft used to couple the engine and gear head on this unit consists of two universal joints with connections to the gear and engine. It has a smooth, mechanically accurate operation that reduces power losses to a minimum. It is of simple metal-to-metal construction with needle-bearing joints at

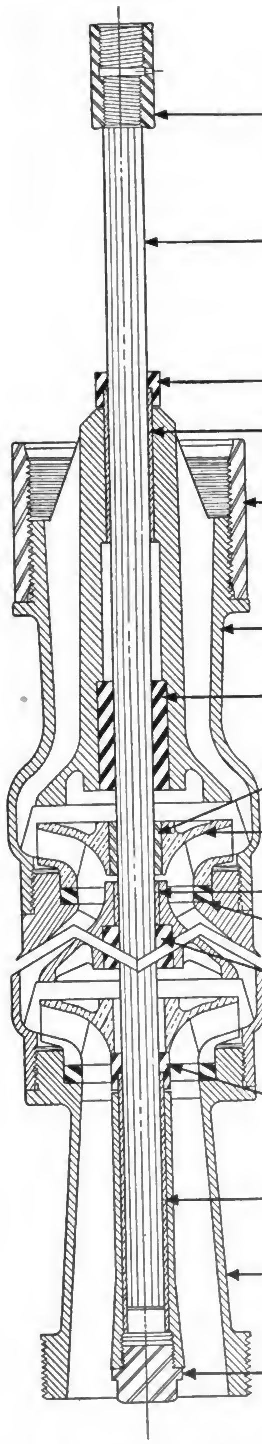


Figure 117. Top and bottom bowls of turbine pump.

each end for flexibility. A tubular connecting shaft carries the torque load, and a splined slip connection accommodates endwise movement. The assembly is light, yet strong. It functions with a complete and universal flexibility in both horizontal and vertical planes, with free end float under all conditions. All parts are balanced, and the assembly operates smoothly, quietly, and without vibration at all speeds and under heavy fixed or variable misalignment.

(6) Engine. The engine power unit is a Model F 140 Continental water-cooled gasoline engine with clutch and power take-off, fuel tank, muffler, and oversize radiator. It is equipped for magneto ignition and hand-crank starting.

(7) Preparation for service. The satisfactory operation of any deep-well turbine pump depends to a large extent upon correct installation of the unit. As no two wells are exactly alike these instructions cannot cover every question that may arise, and the installer must adapt to the conditions of each installation the methods set forth in this outline.

(8) Necessary equipment for installation. The following tools and equipment ordinarily are required to install a deep-well pump:

(a) A permanent derrick or a tripod. If the pump is set as the well is finished, the rig is used.

(b) A winch, cable, and blocks for raising and lowering the pump sections into the well.

(c) Two pairs of chain tongs with sufficient chain to reach around the pump and column.

(d) Two pipe wrenches.

(e) Miscellaneous tools, including hammer, chisel, hacksaw, screw driver, end wrenches, a wire brush for cleaning threads, and wiping rags.

(f) Two pairs of elevators or clamps to fit the outside diameter of the water column.

(g) Wire rope sling sufficiently long to allow the hoist hook to clear the top of the shaft extension when lifting the column.

(h) White lead and machine oil to use on the column threads.

(9) Preparation of pump and well. (a) Pump foundation. A substantial concrete pump foundation should be built around the well with its top extending several inches beyond the pump base on all sides, and the bottom of area sufficient to carry the weight of pump and engine safely to the sustaining soil. I-beams of sufficient length and weight may be placed one on either side of the well, or heavy timbers may be used, instead of the concrete foundation. If the ground will hold the weight of the pump and engine, using the structural steel subbase supplied, no subfoundation is required, but the subbase must not be allowed to settle and throw the equipment out of alignment.

(b) Unloading and preparation of pump parts. Pump parts are carefully removed from the truck at the well site. Parts too heavy to be lifted should be skidded to the ground to aviod breakage, or bending the shafts. A bent shaft invariably causes trouble sooner or later. Thread protectors are not removed from column pipe until ready to use the joint, and planks are used to keep pump parts from dragging on the ground. For detailed directions for installing the pump, refer to the instruction manual furnished with each unit.

137. PEERLESS HI-LIFT PUMP.

a. Description (fig. 118). This pump is especially designed for relatively low capacities and for installation in 4-inch and 6-inch or larger cased wells. The pump has three essential parts. A turbine pump utilizes the effect of whirling water to cause fluid to flow and develop pressure. A plunger pump pushes water, and the pressure is directly applied. In the Hi-Lift pump the flow results from the displacement of a piston in a cylinder of infinite length. In the cross-sectional drawing (fig. 119), it is seen that the pumping element consists of a main body, known as a stator and a rotor, both of helical form, and a drive shaft assembly. The helices really are worm-threads, the stator having a double thread and the rotor a corresponding single thread. The pump is a positive-displacement type. As the rotor rolls on the inner surface of the stator, liquid is squeezed ahead of the rolling action, with minimum turbulence. The continuous rolling action of the rotor, with no lost motion, and the constant displacement cross-section, give a uniform flow. To resist corrosion and abrasion the spiral-shaped rotor is made of heat-treated stainless steel with a hard chrome surface. The positive displacement action makes priming unnecessary. A one-piece bronze strainer with a rubber-seated foot valve keeps the column full of water, and no prelubrication is necessary. The stator is of cutless rubber, and is highly resistant to abrasive action. Grit momentarily depressed into the rubber when the rotor passes over it is washed away by the water when released.

(1) Pump head. The pump head consists of a discharge base (fig. 114) on which is mounted a right-angle-gear drive head (fig. 111).

(2) Column pipe and shaft. The column pipe is standard weight. It is made in 10-foot sections, except the first section below the pump head and the first section above the pumping element, which are 5 feet long. Each end of each piece of pipe is faced and butted in the coupling. The column shaft is turned, ground, and polished precision steel having a hard, noncorrosive-bearing surface. The shafting is in lengths identical with those of the column pipe. Long, cutless-rubber bearings are located

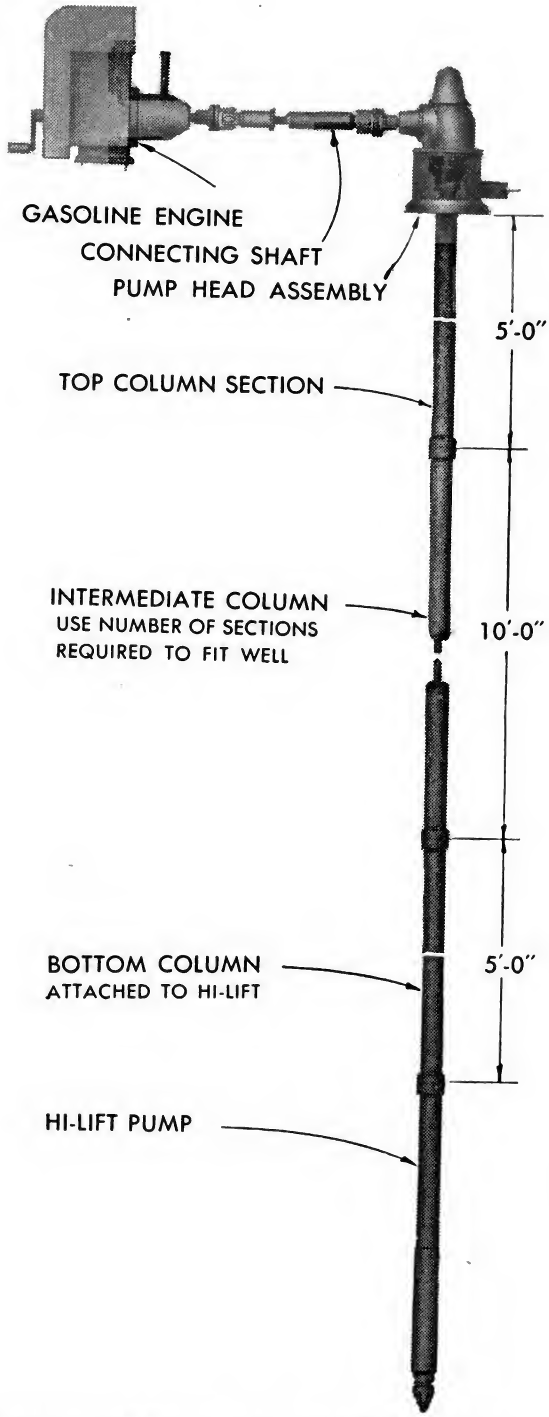


Figure 118. General assembly of the Hi-Lift pump.

at each pipe joint. They are firmly supported in the column pipe, and are lubricated by the water being pumped. The pump column assembly is illustrated in figure 119.

(3) Pumping element. (a) The pumping element consists of a hard heat-treated, chrome-plated, stainless steel helical-contoured rotor, revolving at relatively slow speed, usually 1,800 rpm, inside a cutless rubber, helical-contoured stator, creating a positive pumping action.

(b) The pumping element and the column pipe must be full of water at all times to protect the rubber bearings. Attached to the stator is a combination bronze strainer and dual-seated foot valve. The strainer prevents large particles from entering the pump.

(c) The Hi-Lift pump is furnished in two sizes, with the following capacities:

No. 40 Series	28 to 33 gpm.
No. 50 Series	45 to 57 gpm.

Each size is made in several lengths, the longer elements developing greater pressure. Therefore, each Hi-Lift unit is designated by two numbers, the first signifying the size or series, and the second the length. To illustrate, the Nos. 41 and 42 pumps are No. 40 series pumps; but the No. 42 pump is longer and develops more head than the No. 41.

(d) The Hi-Lift pumps are furnished with 250 feet of column and shafting for a setting of 250 feet. The pumps can be set at 400 feet without any speed change or any modification other than the addition of extra column and shafting. The capacity is approximately the same at their deeper settings.

b. Operating principle. (1) Assume that a forming tool is made of two semicircles united by a rectangular section (see fig. 120). Consider that the stator is made of ice and that the heated forming tool (used like a branding iron) is pressed against it, melting a path. If this tool is steadily revolved as it is fed through the length of the stator, it will generate a helix, as shown in figure 119. Thus, consider that the branding iron is reduced to a simple disk, attached to a shaft, with an offset eccentric center. If this disk were rotated with its eccentric motion, it would feed through one of the stator helices from end to end in the same manner as the original generating form. Then, if the rotor were made in the solid form, and followed the path made by the elemental disk, it would fit snugly into one of the stator helices, leaving the alternate helix void. In one cycle, or revolution, the true center of the rotor describes a complete circular orbit in the opposite direction to that of the rotor rotation. Thus, in one revolution of the driving shaft, the liquid in the open helix is forced around the stator in the same direction.

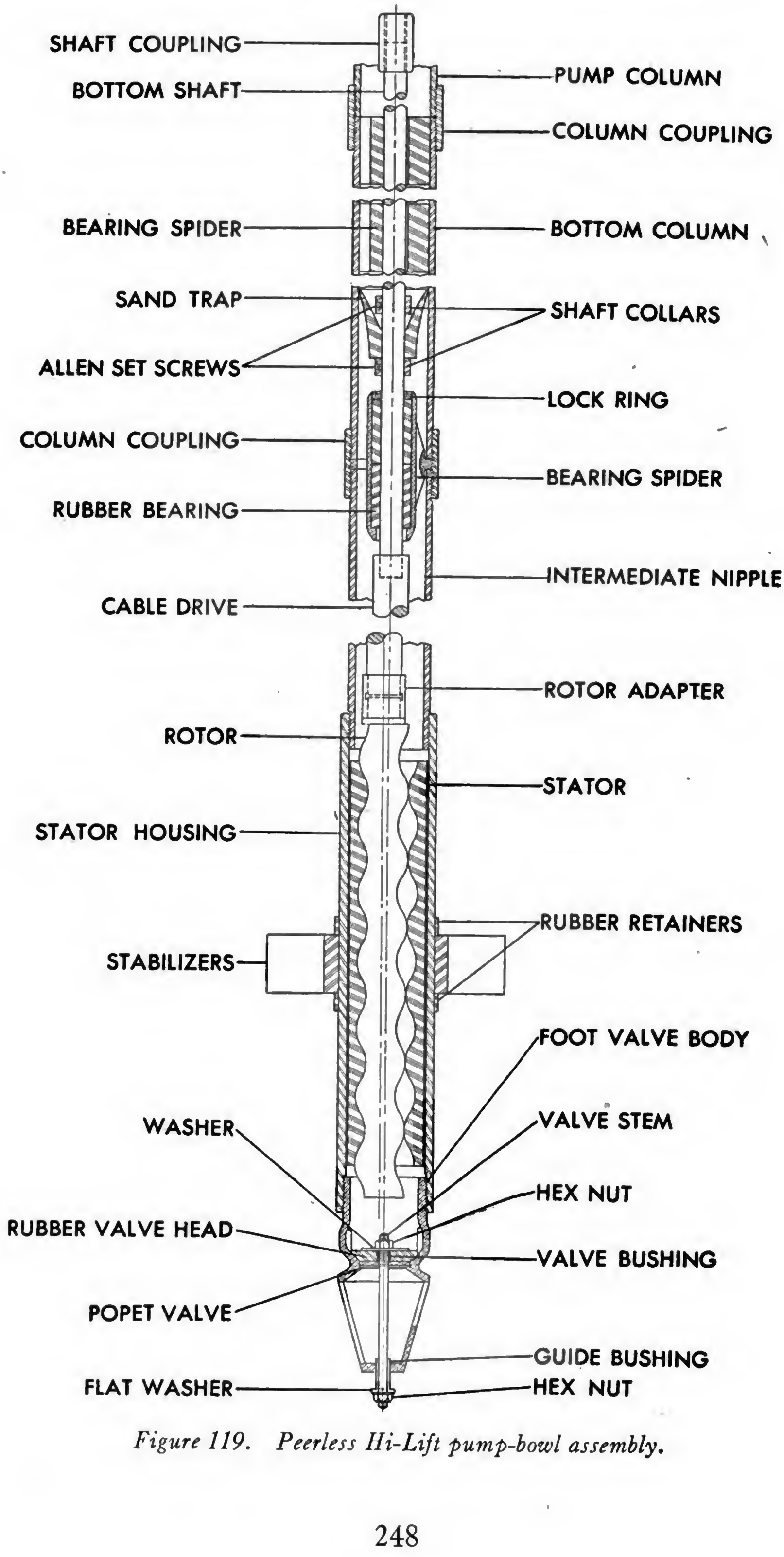


Figure 119. Peerless Hi-Lift pump-bowl assembly.

The speed of flow in relation to the moving element is differential only, and is low by comparison with those developed in other types of pumps.

(2) For detailed instructions in installation of the Hi-Lift pump refer to the directions furnished with each unit.

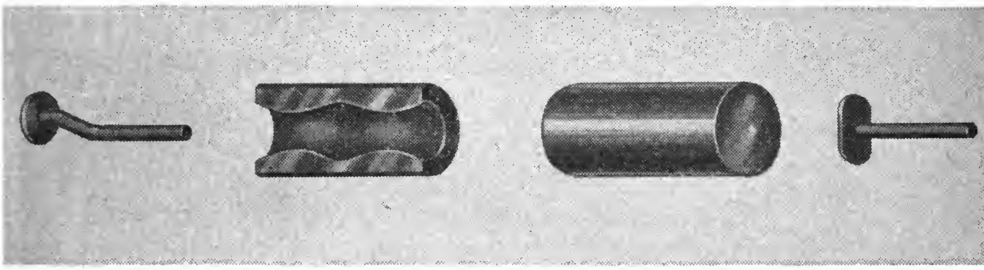


Figure 120. Helix assembly of Hi-Lift pump.

138. AIR-LIFT PUMPS.

a. Description and operation. **(1)** The air lift is used extensively in pumping water or oil from wells. It consists of a discharge pipe and a smaller air pipe, both partially submerged in a well. The air pipe leads to a device for introducing compressed air into the bottom of the discharge pipe in as finely divided a state as possible. This is known as the footpiece, or pump proper, and has a considerable effect upon the efficiency of operation. The mixture of liquid and air formed in the discharge pipe by this method is lighter than the head of liquid outside the pipe; consequently, the mixture rises to the surface. This principle is illustrated in figure 121.

(2) Consider an open well, or a pond, lake, or river. In this source of supply is suspended a vertical pipe for water and a pipe for air. These pipes are submerged for a depth proportionate to the lift when the pump is at work. The water, being free to enter the lower end of the pipe, will rise to the same height inside the pipe as it stands outside, and in this condition there is nothing to cause any movement of the water either upward or downward. If through the air pipe air under pressure is introduced into the base of the water pipe, we have an air-lift pump. Its principle of operation, briefly described, is as follows:

The energy operating the air lift is that energy in a volume of compressed air released in a fluid column in the form of bubbles at or near the end of the submerged portion of the discharge pipe; and the driving force, causing the pump to operate continuously, is the unbalanced hydrostatic pressure in the discharge pipe resulting from the presence of a mixed column of water and bubbles of air of less specific gravity than the outside opposed column of unmodified water.

b. Terms pertaining to air lift. Certain terms used in connection with the operation of an air lift, are defined as follows (see fig. 122):

(1) Elevation. The distance above the ground level at the well, to which it is necessary to deliver the water. This is represented by distance *A* to *B*.

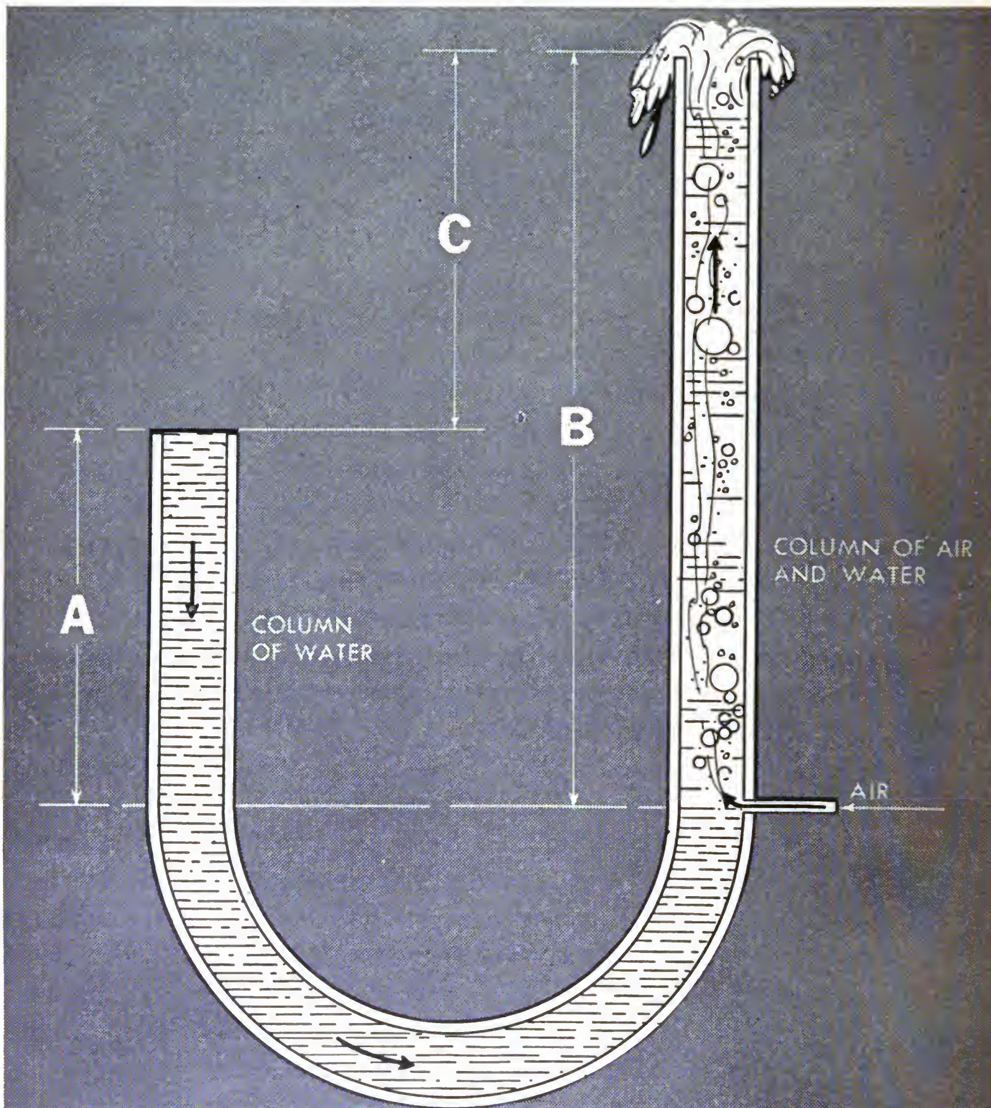


Figure 121. Diagram illustrating the principle of the air-lift pump.

(2) Static head. The distance the water stands below the surface of the ground when not pumping is the static or normal water level. It is the distance *B* to *C*.

(3) Draw-down. The distance the water level declines below the static level when pumping at the desired rate—distance *C* to *D*.

(4) Lift. The lift consists of the static head, plus the draw-down, plus the elevation—distance A to D.

(5) Submergence. (a) Submergence is the distance the pump, or foot piece, is submerged below the pumping level—distance D to E. Submergence usually is expressed in terms of percent of the total length of pipe. For example, if the distance A to E is 200 feet, and the distance A to D, the lift, is 60 feet, the percentage of submergence is

$$\frac{(200-60)}{200}=.70=70 \text{ percent}$$

This means that the total vertical air-lift column, distance A to E, is submerged in the liquid column in the well for a certain percentage of its length.

(b) In operating drilled wells, we find two kinds of submergence: C to E the starting submergence, which fixes the starting air pressure required, and the more important working submergence, distance D to E, which governs the working pressure. The air pressure, in pounds per square inch, required to equalize the water pressure is equal to the submergence, in feet, divided by 2.31.

(c) The pressure required to start the pump is greater than that necessary to keep it in operation, friction neglected, as there will be a progressive lowering of the water level, and consequently a lower head of water over the pump, until the pumping level is reached and the pressure becomes constant.

c. Design of installation. (1) Design of an air lift is based on the yield, the water level, and the dimensions of the well to be pumped. Usually the well is tested for capacity and draw-down when it is drilled, but sometimes the yield and pumping level have to be estimated from experience and from the characteristics of other wells in the neighborhood. From these data the well is piped, corrections being made later if necessary, by raising or lowering the piping in the well.

(2) The length of the discharge pipe can be approximated from the table of best and allowable submergences shown in figure 120. Lower submergences than those shown result in a lower pumping efficiency. Hence, the planned rate of pumpage must not cause an excessive drop in the water level, reducing the submergence.

(3) There are two chief losses in the discharge pipe: the slippage of the air through the water, and the friction of the water in the discharge line. As the velocity of discharge increases the slippage decreases and the friction increases. There is also an entrance loss at the foot piece caused both by friction and by the energy required to accelerate the flow of water into the pipe. Finally, a constant velocity of water through the whole length of

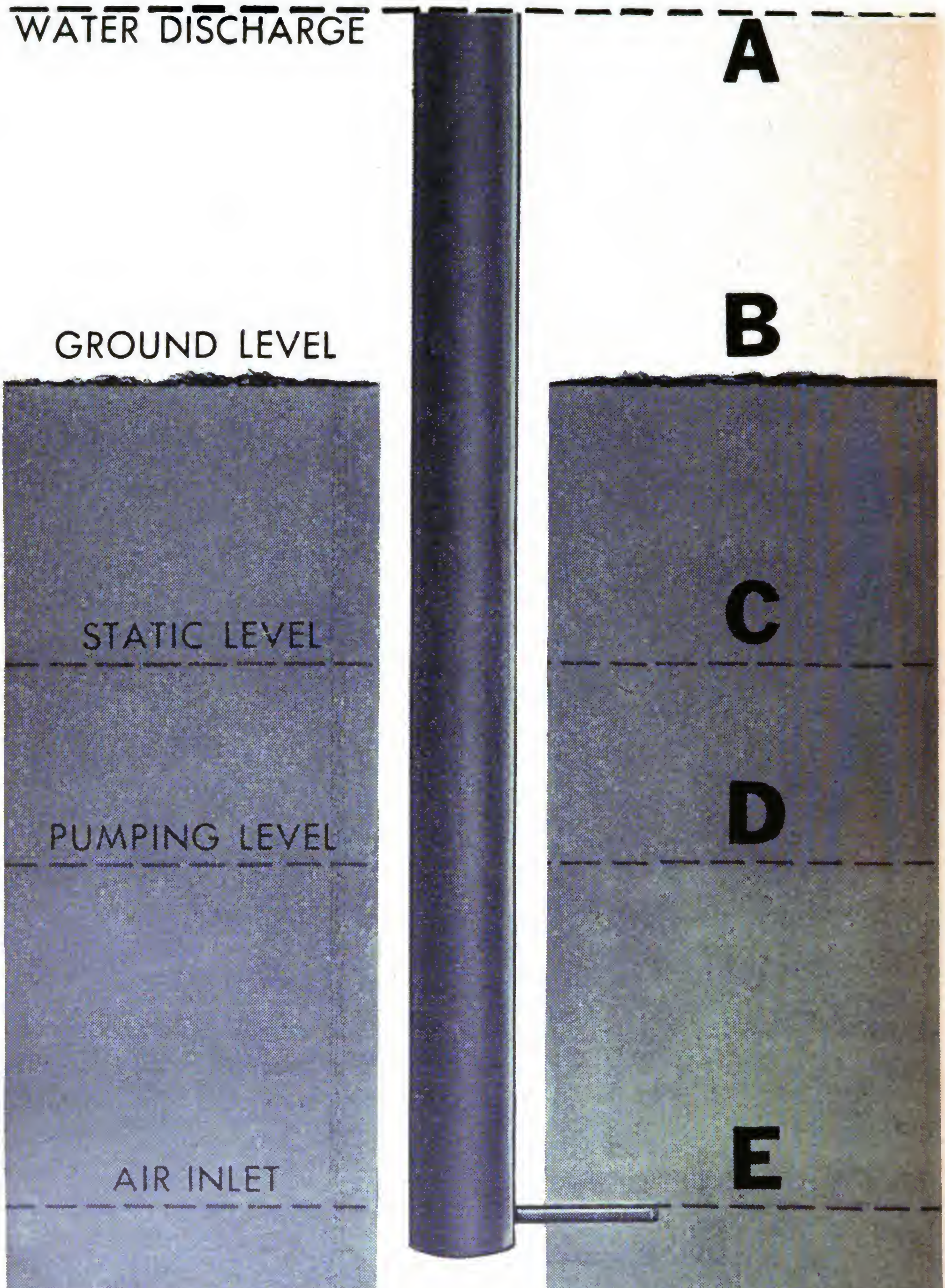


Figure 122. Diagram of well with air-lift pump.

the discharge pipe is desirable, as less work is required to lift a mass at a constant rate than at a constantly increasing velocity. Inlet and discharge velocities therefore are of primary importance.

TABLE VIII. *Customary air lift submergence and correspondence yield from a deep well*

Lift in feet	Submergence percent	Lift percent	Rating	Submergence feet	Starting air pressure lbs./sq. in.	Gallons water per cu. ft. air	Cubic feet of air per gal. water	Total length of air line
25	54	46	Minimum	29	13	4.55	0.22	54
	68	32	Best	53	23	8.34	.12	78
	76	24	Maximum	79	34	14.30	.07	104
50	51	49	Minimum	52	23	2.50	.40	102
	65	35	Best	93	40	4.35	.23	143
	72	28	Maximum	129	56	6.57	.15	179
100	47	53	Minimum	89	38	1.43	.70	189
	60	40	Best	150	65	2.70	.37	250
	67	33	Maximum	203	88	3.70	.27	303
150	43	57	Minimum	113	49	1.05	.95	263
	55	45	Best	183	79	2.04	.49	333
	62	38	Maximum	245	106	2.70	.37	395
200	41	59	Minimum	139	60	.85	1.18	339
	52	48	Best	216	94	1.54	.65	416
	59	41	Maximum	288	125	1.89	.53	488
250	39	61	Minimum	160	69	.71	1.41	410
	49	51	Best	240	104	1.21	.83	490
	56	44	Maximum	318	138	1.45	.69	568
300	37	63	Minimum	176	76	.60	1.67	476
	47	53	Best	266	115	.96	1.04	566
	53	47	Maximum	339	147	1.18	.85	639
350	36	64	Minimum	197	85	.53	1.88	547
	45	55	Best	287	124	.80	1.25	637
	50	50	Maximum	350	151	.94	1.06	700
400	35	65	Minimum	215	93	.48	2.07	615
	43	57	Best	302	130	.69	1.45	702
	48	52	Maximum	369	160	.79	1.26	769
450	34	66	Minimum	232	100	.44	2.27	682
	42	58	Best	326	141	.61	1.65	776
	47	53	Maximum	399	173	.68	1.48	849
500	34	66	Minimum	258	112	.41	2.46	758
	41	59	Best	348	150	.54	1.85	848
	46	54	Maximum	426	184	.60	1.66	926
550	34	66	Minimum	283	123	.38	2.65	833
	40	60	Best	367	159	.49	2.05	917
	45	55	Maximum	450	195	.54	1.86	1000
600	33	67	Minimum	296	128	.36	2.81	896
	40	60	Best	400	173	.45	2.25	1000
	44	56	Maximum	471	204	.49	2.06	1071
650	33	67	Minimum	320	139	.34	2.94	962
	39	61	Best	416	180	.42	2.40	1066
	43	57	Maximum	490	212	.44	2.26	1140
700	33	67	Minimum	345	149	.33	3.00	1045
	39	61	Best	448	194	.39	2.55	1148
	43	57	Maximum	528	228	.42	2.40	1228

(4) With a straight pipe, the best discharge velocity of the mixture of air and water for lifts from 40 to 200 feet ranges from 2,000 feet per minute at 25 percent submergence to 700 feet per minute at 70 percent submergence. With a tapered discharge pipe, the best discharge velocity is 1,400 feet per minute at 35 percent submergence, and 550 feet per minute at 70 percent submergence. The best velocity for the mixture of water and air at the entrance of the bottom of the discharge pipe is 800 feet per minute at 35 percent submergence, and 450 feet per minute at 70 percent submergence.

(5) The required size of the discharge pipe may be found from the formula:

$$Q=av$$

where:

Q=quantity of the mixture of air and water, in cubic feet per second.

a=cross-sectional area of the discharge pipe, in square feet.

v=velocity of mixture in pipe, in feet per second.

The quantity, Q, at any point in the discharge pipe is the volume of the water to be pumped plus the volume of compressed air at that point. Since the air expands as it passes up the discharge pipe under decreasing head, the air volume differs from that of compressed air at inlet pressure to that of free air at the point of discharge. To maintain the recommended velocity range, frequently it is necessary to use larger pipe in the upper sections of the well than in the lower section. This arrangement is known as a "tapered" discharge pipe, and is recommended for most installations.

(6) The proper size air pipe to use depends upon the volume and pressure of the air to be transmitted and usually is determined from manufacturers' tables, mechanical computers, and similar sources. The diameter of the well and the method of piping often limit the size of the air pipe, and considerable latitude therefore is allowable. Ordinary practice places velocities between 30 and 40 feet per second, although these figures frequently are exceeded, and smaller air pipes than generally recommended give better results up to the point where friction becomes excessive. In general the friction loss should not exced 3 pounds per square inch.

(7) From the standpoint of efficiency, it is important that the compressor deliver the correct amount of air. Too much air causes excessive friction in the pipe lines, an unnecessarily high receiver pressure, and a waste of air from incomplete expansion in the discharge pipes. Too little air results in a reduced yield and in a surging, intermittent discharge.

(8) In some wells, the difference between the static and pumping heads may be enough to make the starting pressure so much higher than the

running pressure as seriously to overload the air compressor. The compound air lift overcomes this difficulty. It consists of a standard air-lift pump with a supplementary auxiliary or starting pump, which is placed above the standard air-lift pump. Its submergence with respect to the static head utilizes the maximum pressure of which the compressor is capable without dangerous overload.

(9) When starting a well, the air first is turned on to the auxiliary pump which, as the water level lowers, gradually is turned off and the standard pump brought into operation.

(10) The device used to connect the air pipe and discharge pipe, and to admit compressed air into a column of water, is commonly called the "pump" or "foot piece." The foot piece is chosen on the following basis:

(a) It should divide the air into small streams without much loss in pressure.

(b) The air outlet rings should be spaced properly to prevent any sudden rush of air and lightening of the discharge column.

(c) There should be no moving parts.

(d) It should be designed to give an unobstructed water passage, that is, it should have a cross-sectional area equal to that of the discharge pipe at the bottom.

(e) It should be so designed that scale and dirt passing down the air or discharge pipe will not clog the holes but will pass through the pump and fall to the bottom of the well.

d. Installation. Air-lift pumping is a simple method for testing a well. In using the air lift the following data are obtained:

(1) Determine from records of nearby wells, driller's experience, and other sources, the approximate yield to be expected from the well and the probable draw-down at this capacity. Measure the depth to the static water level in the well.

(2) From the depth of the well or the maximum compressor-starting pressure (whichever is the determining factor) determine the working submergence, percent of submergence, starting submergence, and starting and working pressures. See figure 120 as a key to determining the above factors.

(3) Knowing the percent submergence, determine the best size discharge for this condition (see table III). For ordinary purposes, a 1-inch air line is adequate when used with a 3- or 4-inch drop pipe.

(4) Knowing the lift and percent submergence, estimate from figure 120 the cubic feet of free air per gallon required.

(5) Knowing the cubic feet of free air per gallon and the working and starting pressures, choose a compressor that meets these requirements.

(6) After estimating the air-line size, as previously described, pipe the

well with the lengths and diameters of discharge and air line as calculated. Be certain the bottom of the discharge pipe is at least 5 feet below the bottom of the air line, to prevent air from blowing out around the discharge pipe instead of up through it. Attach a footpiece to the lower end of the air line. The top of the discharge should be piped so that the water will flow into a suitable measuring tank. This is best accomplished by threading one side of the run of a standard "T" to the discharge pipe through the run of the "T" and packing the space between the top of the run of the "T" and the air line with a reducing bushing and rags, or soft packing, to prevent the water from flowing out at the top, but allowing it to flow horizontally through the base of the "T." A suitable elbowhead piece as shown in figure 122 can be used, but is essential only if the installation is to be permanent. Connect the air line to the compressor discharge, and place a reliable pressure gauge in the air line on the downstream side of any valve.

(7) The test of the well determines the following quantities:

(a) Gallons per minute, measured in the measuring tank either by a calibrated weir or by filling the tank and dividing the capacity in gallons by the time, in minutes, required to fill it.

(b) The depth to the water level below the ground level when pumping this measured yield. This is calculated as follows:

H=depth to the water level below ground level, in feet, at the measured yield, in gallons per minute.

L=distance from bottom of air line to ground level, in feet.

P=shut-in pressure, in pounds per square inch.

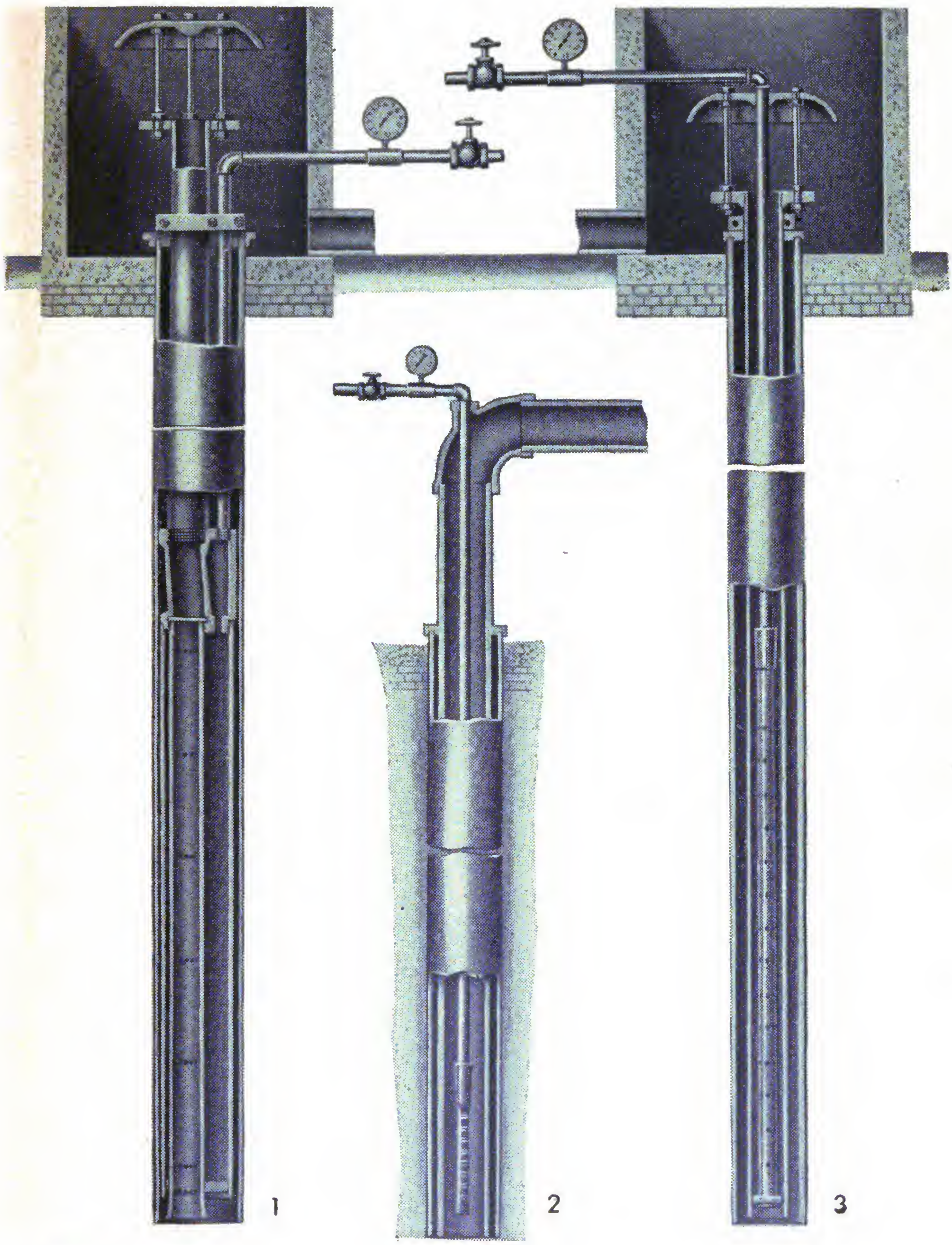
$H=L-2.31\ P.$

The shut-in pressure P is obtained by reading the pressure gauge an instant after the valve between the compressor discharge or receiver and the well has been closed. The shut-in pressure plus the friction of the air in the line equals the working pressure. By obtaining H and the yield in gallons per minute for each of 6 or 8 runs from low to maximum capacity of the compressor, data can be obtained for plotting the yield of the well against the draw down of the water level.

(c) Use the central air-line system, because if the conditions are different from those originally estimated the air and discharge pipes can more easily be raised or lowered than with an outside air-line system. Often it is advisable to put in more than sufficient discharge pipe and to raise or lower the air line as the conditions found in the test dictate.

(d) Measure accurately the length of the air line in the well, as this is the most important factor in the calculation.

(e) Be certain the pressure gauge is accurate, near the well, and on the downstream side of all valves.



1. *Outside air pipe.*
2. *Inside air pipe.*
3. *Inside air pipe discharging into a pump.*

Figure 123. Three types of air-lift pumps.

(f) There should be no unloaders on the compressor. When varying the capacity of the compressor for the several runs it is necessary to slow down the compressor or throttle the intake. If unable to do either, drain a constant quantity of compressed air from the receiver.

(g) Each run should be run long enough, with a constant quantity of compressed air delivered to the pump, to see that the pressure gauge does not vary as much as 1 pound in half an hour.

(h) After conditions have become constant each run should be continued long enough to get a reliable measurement of the average yield of the well. If the measuring tank is small, take several tankfuls to obtain a good average before shutting off the air, to obtain the "shut-in" pressure.

(i) Be certain that water overflowing from the measuring tank is not flowing back into the well, and if the tested well is near other wells be certain the other wells are being pumped, so the well is tested under actual pumping conditions.

(8) Footpieces are more practical than open-end air lines for the following reasons: they break the air into small bubbles, thus completely intermingling the air and water in the discharge pipe; they do not throttle or obstruct the flow of either air or water into the discharge pipe. The footpiece shown has a number of small, circular holes to break up the air into small bubbles, and the area of flow is approximately the same as that of the discharge pipe.

APPENDIX I

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Ingersoll-Rand Company, New York, N. Y.
Edward E. Johnson, Incorporated, St. Paul, Minnesota.
F. E. Meyer and Brother Company, Ashland, Ohio.
Peerless Pump Division, Food Machinery Corporation, Canton, Ohio.
The Star Drilling Machine Company, Akron, Ohio.

APPENDIX II

USEFUL INFORMATION FOR WELL DRILLERS

1. EQUIVALENT WEIGHTS AND MEASURES.

a. Length.

1 millimeter=.03937 inch

1 centimeter=.3937 inch

1 meter=39.37 inches
3.2808 feet

Circumference of a circle=3.1416 × diameter

1 mile=5,280 feet
1.60935 kilometers
.868 knots
8 furlongs

b. Area.

1 acre=43,560 square feet

Area of a circle $=3.1416\times\frac{D^2}{4}$

1 acre foot=43,560 cubic feet
325,900 gallons

1 barrel=42 gallons

c. Weight.

1 gram=1 cubic centimeter of distilled water
15.43 grains troy
.0353 ounce
1 kilogram=2.20462 pounds avoirdupois
1 metric ton=2204.6 pounds
1 cubic foot of concrete (1:2:4)=146 pounds
1 cubic foot of water=62.46 pounds
1 cubic foot of sea water=63.9 pounds
1 cubic foot of bronze=.32 pound
1 cubic foot of cast iron=.26 pound
1 cubic inch of steel=.28 pound

U. S. GALLONS IN ROUND TANKS

For 1 foot in depth

Diameter of tanks (feet)	Number U. S. gals.	Cu. ft. and area in sq. ft.	Diameter of tanks (feet)	Number U. S. gals.	Cu. ft. and area in sq. ft.
1.0	5.87	.785	11.0	710.90	95.03
1.5	13.22	1.767	11.5	776.99	103.87
2.0	23.50	3.142	12.0	845.35	113.10
2.5	36.72	4.909	12.5	918.	122.72
3.0	52.88	7.069	13.0	992.91	132.73
3.5	71.97	9.621	13.5	1070.80	143.14
4.0	94.	12.566	14.0	1151.50	153.94
4.5	118.97	15.90	14.5	1235.30	165.13
5.0	146.88	19.63	15.0	1321.90	176.71
5.5	177.72	23.76	15.5	1411.50	188.69
6.0	211.51	28.27	16.0	1504.10	201.06
6.5	248.23	33.18	16.5	1599.50	213.82
7.0	287.88	38.48	17.0	1697.90	226.98
7.5	330.48	44.18	17.5	1799.30	240.53
8.0	376.01	50.27	18.0	1903.60	254.47
8.5	424.48	56.75	18.5	2010.80	268.80
9.0	475.89	63.62	19.0	2120.90	283.53
9.5	530.24	70.88	19.5	2234.	298.65
10.0	587.52	78.54	20.0	2350.10	314.16
10.5	640.74	86.59			

NOTE 1. 42 gallons=1 barrel.

2. To find the capacity of tanks greater than the largest given in the table, look in the table for a tank of one-half of the given size and multiply its capacity by 4, or one of one-third its size and multiply its capacity by 9, etc.

d. Volume.

1 cubic foot=7.4805 gallons
231 cubic inches
.8333 Imperial gallons
1,000,000 gallons=3.0689 acre feet
1 liter=61.023 cubic inches
.264 gallons

Volume of a sphere $=3.1416\times\frac{D^3}{6}$

e. Temperature.

Degrees C $=\frac{5}{9}\times(F-32)$ Degrees F $=\frac{9}{5}\times C+32$

f. Comparative equivalents of liquid measures and weights.

Measures and weights for comparison	Measure and weight equivalents of items in first column				
	U. S. gallons	Imperial gallons	Cubic inches	Cubic feet	Cubic meter
U. S. gallon	1.	.833	231.	.1337	.00378
Imperial gallon	1.20	1.	277.27	.1604	.00454
Cubic inch	.0043	.00358	1.	.00057	.000016
Cubic foot	7.48	6.235	1728.	1.	.02827
Cubic meter	264.17	220.05	61023.	35.319	1.
Liter	.26417	.2200	61.023	.0353	.001
* Vedro	3.249	2.706	750.1	.4344	.01228
* Pood	4.328	3.607	1000.	.578	.01636
Pound	.12	.1	27.72	.016	.00045

Measures and weights for comparison	Measure and weight equivalents of items in first column—Continued.			
	Liters	* Vedro	* Pood	Pounds
U. S. gallon	3.785	.308	.231	8.33
Imperial gallon	4.542	.369	.277	10.
Cubic incn	.0163	.00132	.001	.0358
Cubic foot	28.312	2.304	1.728	62.355
Cubic meter	1000.	81.364	61.023	2200.54
Liter	1.	.08136	.06102	2.2005
* Vedro	12.29	1.	.7501	27.06
* Pood	16.381	1.333	1.	36.07
Pound	.454	.0369	.0277	1.

* Vedro and pood are a Russian measure and weight respectively.

g. Pressure.

1 atmosphere=

760 millimeters of mercury at 32° F.
14.7 pounds per square inch.
29.921 inches of mercury at 32° F.
2,116 pounds per square foot.
1.033 kilograms per square centimeter.
33.947 feet of water at 62° F.

1 foot of air at 32° F. and barometer 29.92=

.0761 pound per square foot.
.0146 inch of water at 62° F.

1 foot of water at 62° F.=

.433 pound per square inch.
62.355 pounds per square foot.
.883 inch of mercury at 62° F.
821.2 feet of air at 62° F. and barometer 29.92.

1 inch of water 62° F.=

.0361 pound per square inch.
5.196 pounds per square foot.
.5776 ounce per square inch.
.0735 inch of mercury at 62° F.
68.44 feet of air at 62° F. and barometer 29.92.

1 pound per square inch=

2.0355 inches of mercury at 32° F.
2.0416 inches of mercury at 62° F.
2.309 feet of water at 62° F.
.07031 kilogram per square centimeter.
.06804 atmosphere.
51.7 milimeters of mercury at 32° F.

h. Mechanical and electrical units.

1 B.t.u.=

1,054 watt seconds.
777.5 foot-pounds.
107.5 kilogram-meters.
.0003927 horsepower hour.

1 foot-pound=

1.3558 joules.
.13826 kilogram-meter.
.001286 B.t.u.
.03241 gram-calorie.
.000000505 horsepower hour.

1 horsepower=

745.7 watts.
.7457 kilowatts.
33,000 foot-pounds per minute.
641,700 gram-calories per hour.
273,743 kilogram-meters per hour.
2,547 B.t.u. per hour.

1 joule=

1 watt second.
.10197 kilogram-meter.
.73756 foot-pound.
.239 gram-calorie.
.0009486 B.t.u.

1 kilogram-meter=

7.233 foot-pounds.
9.806 joules.
2.344 gram-calories.
.0093 B.t.u.

1 kilowatt=

1,000 watts.

1.341 horsepower.

2,655,200 foot-pounds per hour.

860,500 gram-calories per hour.

367,000 kilogram-meters per hour.

3,415 B.t.u. per hour.

.102 boiler horsepower.

i. Hydraulic equivalents—miscellaneous.

(1) Specific gravity of water at 60° F.=1.0.

(2) Viscosity of water at 60° F.=31.5 S.S.U. (seconds Sayboldt Universal).

(3) Conversion factors:

Feet head x .434 x specific gravity=pounds pressure per square inch.

Pounds pressure x 2.31÷specific gravity=feet head.

Meters x 3.28=feet head.

1 acre-inch (quantity of water required to cover 1 acre to a depth of 1 inch)=27,152 gallons.

1 acre-inch in 12 hours pumping=37.7 gallons per minute.

Inches of mercury x 1.133=feet-head of water.

Barrels per day x 0.02917=gallons per minute (if barrel has 42 gallons).

(4) Velocity of flow formula:

$$\text{Velocity of flow in a pipe in feet per second} = \frac{\text{gpm x .408}}{(\text{diameter in inches})^2}.$$

(5) Doubling the diameter of a pipe increases its capacity four times.

(6) Approximately every foot elevation of a column of water produces a pressure of ½ pound per square inch.

(7) The gallons per minute which a pipe will deliver equals .0408 times the square of the diameter, multiplied by the velocity in feet per minute.

(8) To find the capacity of a pipe or cylinder in gallons, multiply the square of the diameter in inches by the length in inches and by .0034.

(9) The weight of water in any length pipe is obtained by multiplying the length in feet by the square of the diameter in inches and by .34.

(10) To find the discharge from any pipe in cubic feet per minute, square the diameter and multiply by the velocity in feet per minute and by .00545.

(11) Flowing water:

1 cubic foot per minute=7.4805 gallons per minute

1 second foot=

1 cubic foot per second

448.83 gallons per minute

1 second—foot—day=2 acre-feet

2. PUMPING DATA.

a. Definitions. (1) Static suction lift is the vertical distance in feet from the center line of the pump to the free level of the liquid to be pumped, when the free level is below the center line of the pump.

(2) Total dynamic suction lift is the vertical distance in feet from the center line of the pump to the free level of the liquid to be pumped plus the velocity head plus all friction losses in the suction pipe and fittings.

(3) Total dynamic suction lift, as determined by test, is the reading of a mercury column or vacuum gauge connected to the suction nozzle of the pump, plus the vertical distance between the point of attachment of the mercury column to the center of the pump, plus the head of water resting on the mercury column, if any.

(4) Static suction head is the vertical distance in feet from the center line of the pump to the free level of the liquid to be pumped.

(5) Total dynamic suction head is the vertical distance in feet from the center line of the pump to the free level of the liquid to be pumped minus the velocity head and minus all friction losses in suction pipe and fittings.

(6) Total dynamic suction head, as determined by test, is the reading of a gauge connected to the suction nozzle of the pump, minus the vertical distance from the center of the gauge to the center of the line pump.

(7) Total static head is the vertical distance in feet between the free level of the source of supply and the point of free discharge or from the source of supply to the level of the free surface of the discharge water.

(8) Total dynamic head is the vertical distance in feet between the free level of the source of supply and the point of free discharge or from the free level of the source of supply to the level of the free surface of the discharge water, plus velocity head and all friction losses.

(9) Total dynamic head, as determined by test, where suction lift exists, is the reading of a mercury column or vacuum gauge connected to the suction nozzle of the pump, plus the reading of a pressure gage connected to the discharge nozzle of the pump, plus the vertical distance between the point of attachment of the mercury column and the center of the gauge, plus excess, if any, of velocity head of discharge over velocity head of suction as measured at points where the instruments are attached, plus head of water resting on mercury column, if any.

(10) Total dynamic head, as determined by test, where suction head exists, is the reading on a gauge attached to the discharge nozzle of the pump, minus the reading of the gauge connected to the suction nozzle of the pump, plus or minus the vertical distance between the

centers of the gauges (depending on whether the suction gauge is below or above the discharge gauge), plus excess, if any, of velocity head of discharge over velocity head of suction as measured at points where instruments are attached.

(11) Discharge pressure or head. Water pressure frequently is spoken of as head because height of water and pounds-per-square-inch pressure exerted by this height bear a very close relation to each other, affected in a very slight degree by temperature. For all ordinary pump calculations it is sufficiently accurate to consider that the pressure of 1 foot of water is equivalent to 0.434 pound per square inch, and that 1 pound per square inch is the pressure of 2.3 feet of water.

(12) Velocity head, sometimes called the head due to velocity, is the equivalent head in feet through which the water would have to fall to acquire the same velocity, or in other words, the head necessary to accelerate the water. (For table of velocity heads, see *c*(2) below)

$$h=\frac{V^2}{2g}$$

Where V=velocity of the water through the pipe in feet per second.
Where h=head in feet (velocity head).
Where g=32.2 feet per second, acceleration due to gravity.

(13) Water horsepower is obtained from the formula

$$\text{Water hp}=\frac{\text{gallons per minute} \times \text{head in feet} \times \text{specific gravity}}{3{,}960}$$

NOTE. The constant 3,960 is obtained by dividing the number of foot pounds for one horsepower (33,000) by the weight of one gallon of water (8.33 pounds).

or

$$\frac{\text{gallons per minute} \times \text{head in pounds per square inch}}{1{,}714}$$

(14) Brake horsepower is obtained from the formula:

$$\text{Brake hp}=\frac{\text{water hp}}{\text{efficiency of pump}}$$

(15) Efficiency (water to water) $=\dfrac{\text{gpm} \times \text{total head in feet}}{3{,}960 \times \text{brake hp to pump}}$

(16) Field overall efficiency $=\dfrac{\text{gpm} \times \text{total head in feet}}{3{,}960 \times \text{input hp to pump motor}}$

b. Pressure and discharge tables. (1) Table of pressures in pounds per square inch with equivalent feet head.

Pressure in pounds per square inch	0	1	2	3	4	5	6	7	8	9
	Equivalent feet head									
5	115.2	117.5	119.8	122.1	124.4	126.7	129.0	131.3	133.6	135.9
6	138.2	140.5	142.8	145.1	147.4	149.7	152.0	154.3	156.6	158.9
7	161.2	163.5	165.8	168.1	170.4	172.7	175.0	177.3	179.6	181.9
8	184.3	186.6	188.9	191.2	193.5	195.8	198.1	200.4	202.7	205.0
9	207.3	209.6	211.9	214.2	216.5	218.8	221.1	223.4	225.7	228.0
10	230.4	232.7	235.0	237.3	239.6	241.9	244.2	246.5	248.8	251.1
11	253.4	255.7	258.0	260.3	262.6	264.9	267.2	269.5	271.8	274.1
12	276.4	278.7	281.0	283.3	285.6	287.9	290.2	292.5	294.8	297.1
13	299.5	301.8	304.1	306.4	308.7	311.0	313.3	315.6	317.9	320.2
14	322.5	324.8	327.1	329.4	331.7	334.0	336.3	338.6	340.9	343.2
15	345.6	347.9	350.2	352.5	354.8	357.1	359.4	361.7	364.0	366.3
16	368.6	370.9	373.2	375.5	377.8	380.1	382.4	384.7	387.0	389.3
17	391.6	393.9	396.2	398.5	400.8	403.1	405.4	407.7	410.0	412.3
18	414.7	417.0	419.3	421.6	423.9	426.2	428.5	430.8	433.1	435.4
19	437.7	440.0	442.3	444.6	446.9	449.2	451.5	453.8	456.1	458.4
20	460.8	463.1	465.4	467.7	470.0	472.3	474.6	476.9	479.2	481.5
21	483.8	486.1	488.4	490.7	493.0	495.3	497.6	499.9	502.2	504.5
22	506.8	509.1	511.4	513.7	516.0	518.3	520.6	522.9	525.2	527.5
23	529.9	532.2	534.5	536.8	539.1	541.4	543.7	546.0	548.3	550.6
24	552.9	555.2	557.5	559.8	562.1	564.4	566.7	569.0	571.3	573.6
25	576.0	578.3	580.6	582.9	585.2	587.5	589.8	592.1	594.4	596.7
26	599.0	601.3	603.6	605.9	608.2	610.5	612.8	615.1	617.4	619.7
27	622.0	624.3	626.6	628.9	631.2	633.5	635.8	638.1	640.4	642.7
28	645.1	647.4	649.7	652.0	654.3	656.6	658.9	661.2	663.5	665.8
29	668.1	670.4	672.7	675.0	677.3	679.6	681.9	684.2	686.5	688.8

Example: In order to find the equivalent feet head for 136 pounds follow down the first column to the figure 13, then across on the same horizontal line until under the figure 6, which gives 313.3 feet as the equivalent to 136 pounds pressure.

(2) Flow of water in gallons per minute through smooth-bore hose .*

Fluid pressure

Hose (internal diameter inches)	Pounds per square inch									
	20	30	40	50	60	70	80	90	100	125
1.00	23	28	33	37	40	43	46	49	52	58
1.25	40	50	57	64	70	76	81	86	90	101
1.50	64	78	90	101	111	120	128	135	143	159
2.00	130	159	184	206	227	242	262	275	292	326
2.50	226	278	322	358	394	425	455	482	509	566
3.00	356	437	504	570	620	665	715	755	800	890
4.00	745	910	1,055	1,180	1,292	1,395	1,492	1,582	1,670	1,850

*The above table is based on a 100-foot length of hose, laid in a straight line with open discharge end. For each set of couplings, deduct 5 percent.

(3) Suction lift of pumps at various altitudes.

Altitude above sea level		Barometric pressure (pounds per sq. in.)	Equivalent head of water (feet)	Practical suction lift of pump (feet)
Feet	Miles			
0	0	14.70	33.95	25
1,320	¼	14.02	32.38	24
2,640	½	13.33	30.79	23
3,960	¾	12.66	29.24	21
5,280	1	12.02	27.76	20
6,600	1 ¼	11.42	26.38	19
7,920	1 ½	10.88	25.13	18
10,560	2	9.88	22.82	17

(4) Theoretical discharge of nozzles in U. S. gallons per minute.

Head		Velocity of discharge (feet per sec.)	Diameter of nozzle in inches									
Pounds	feet		1/16	1/8	3/16	1/4	3/8	1/2	5/8	3/4	7/8	1
10	23.1	38.6	0.37	1.48	3.32	5.91	13.3	23.6	36.9	53.1	72.4	94.5
15	34.6	47.25	0.45	1.81	4.06	7.24	16.3	28.9	45.2	65.0	88.5	116.
20	46.2	54.55	0.52	2.09	4.69	8.35	18.8	33.4	52.2	75.1	102.	134.
25	57.7	61.0	0.58	2.34	5.25	9.34	21.0	37.3	58.3	84.0	114.	149.
30	69.3	66.85	0.64	2.56	5.75	10.2	23.0	40.9	63.9	92.0	125.	164.
35	80.8	72.2	0.69	2.77	6.21	11.1	24.8	44.2	69.0	99.5	135.	177.
40	92.4	77.2	0.74	2.96	6.64	11.8	26.6	47.3	73.6	106.	145.	189.
45	103.9	81.8	0.78	3.13	7.03	12.5	28.2	50.1	78.2	113.	153.	200.
50	115.5	86.25	0.83	3.30	7.41	13.2	29.7	52.8	82.5	119.	162.	211.
55	127.0	90.4	0.87	3.46	7.77	13.8	31.1	55.3	86.4	125.	169.	221.
60	138.6	94.5	0.90	3.62	8.12	14.5	32.5	57.8	90.4	130.	177.	231.
65	150.1	98.3	0.94	3.77	8.45	15.1	33.8	60.2	94.0	136.	184.	241.
70	161.7	102.1	0.98	3.91	8.78	15.7	35.2	62.5	97.7	141.	191.	250.
75	173.2	105.7	1.01	4.05	9.08	16.2	36.4	64.7	101.	146.	198.	259.
80	184.8	109.1	1.05	4.18	9.39	16.7	37.6	66.8	104.	150.	205.	267.
85	196.3	112.5	1.08	4.31	9.67	17.3	38.8	68.9	108.	155.	211.	276.
90	207.9	115.8	1.11	4.43	9.95	17.7	39.9	70.8	111.	160.	217.	284.
95	219.4	119.0	1.14	4.56	10.2	18.2	41.0	72.8	114.	164.	223.	292.
100	230.9	122.0	1.17	4.67	10.05	18.7	42.1	74.7	117.	168.	229.	299.

NOTE.—The actual quantities will vary from these figures, the amount of variation depending upon the shape of nozzle and size of pipe at the point where the pressure is determined. With smooth taper nozzles the actual discharge is about 94 percent of the figures given in the tables.

(5) Maximum quantities of water which may be pumped through 100 feet of wrought iron pipe at various pressures.

Size pipe (pressure)	½	¾	1	1¼	1½	2	2½	3	4
17 lb	3.2	9.1	18.7	33.5	51.6	106	200	290	589
30 lb	5	14	28	52	78	160	308	436	885
40 lb	6	16	33	60	90	184	350	504	1,023
50 lb	6.5	17.5	37	70	101	206	390	564	1,143
60 lb	7	19.5	40	76	110	226	430	617	1,252
75 lb	7.5	22	45	85	123	253	480	690	1,400
100 lb	9	25	52	99	142	292	558	797	1,607

(6) Relative quantities of water delivered in 1 minute, in 1 hour, and in 24 hours.

Gal. in 1 min.	Gal. in 1 hour	Gal. in 24 hours	Gal. in 1 min.	Gal. in 1 hour	Gal. in 24 hours	Gal. in 1 min.	Gal. in 1 hour	Gal. in 24 hours
3.4	208	5,000	138.8	8,333	200,000	486.1	29,166	700,000
6.9	416	10,000	173.6	10,416	250,000	520.8	31,250	750,000
10.4	625	15,000	208.3	12,500	300,000	555.5	33,333	800,000
13.8	833	20,000	243.0	14,583	350,000	590.2	35,416	850,000
17.3	1,041	25,000	277.7	16,666	400,000	625.0	37,500	900,000
34.7	2,083	50,000	312.5	18,750	450,000	659.7	39,583	950,000
41.6	2,500	60,000	347.2	20,833	500,000	694.3	41,666	1,000,000
52.9	3,125	75,000	381.9	22,916	550,000	1,041.7	62,500	1,500,000
69.4	4,166	100,000	416.7	25,000	600,000	1,388.0	83,333	2,000,000
104.1	6,250	150,000	451.3	27,083	650,000	1,736.0	104,166	2,500,000

c. Pipe and Machinery data. (1) Standard pipe data.

Butt weld

Size (inches)	Diameters: External (inches)	Diameters: Internal (inches)	Weight per foot: Plain ends (pounds)	Weight per foot: Threads and couplings (pounds)	Outside diameter couplings (inches)
⅛	0.405	0.265	0.244	0.245	0.562
¼	.540	.360	.424	.425	.685
⅜	.675	.489	.567	.568	.848
½	.840	.618	.850	.852	1.024
¾	1.050	.820	1.130	1.134	1.281
1	1.315	1.043	1.678	1.684	1.575
1¼	1.660	1.374	2.272	2.281	1.950
1½	1.900	1.604	2.717	2.731	2.218
2	2.375	2.059	3.652	3.678	2.760
Lap weld					
1¼	1.660	1.374	2.272	2.281	1.950
1½	1.900	1.604	2.717	2.731	2.218
2	2.375	2.059	3.652	3.678	2.760
2½	2.875	2.459	5.793	5.819	3.276
3	3.500	3.058	7.575	7.616	3.948
3½	4.000	3.538	9.109	9.202	4.591
4	4.500	4.016	10.790	10.889	5.091
4½ *	5.000	4.496	12.538	12.642	5.591
5	5.563	5.037	14.617	14.810	6.296
6	6.625	6.053	18.974	19.185	7.358

(2) Table of velocities and corresponding velocity heads.*

Velocity (feet per second)	Velocity head (feet)	Velocity (feet per second)	Velocity head (feet)
1	0.02	9	1.25
2	.06	10	1.55
3	.14	11	1.87
4	.25	12	2.24
5	.39	13	2.62
6	.56	14	3.05
7	.76	15	3.50
8	1.01		

* With centrifugal pumps, it is standard practice to give head in feet, not in pounds per square inch. For reciprocating pumps, head always is given in terms of pounds per square inch.

(3) Horsepower ratings and maximum lengths for deep well turbine shaftings (based on turned, ground, and polished shaft).

Rpm of pump	Diameter of shaft (inches)						
	1	1 3/16	1 1/2	1 11/16	1 15/16	2 3/16	2 7/16
730	10	16	35	61	81	120	160
870	12	19	40	60	95	140	190
970	14	21	46	67	106	160	210
1,160	16	26	55	81	129	200	254
1,460	20	32	75	102	162	250	350
1,760	25	40	90	125	200	300	400
2,900	40	62					
3,460	50	75					
Maximum shaft length	400	450	550	600	650	675	700

NOTE 1. Table based on a safety factor of 10.
2. If horsepower ratings are increased, maximum shaft lengths must be decreased. Refer to the manufacturers for recommendations.
3. For stainless steel shafting the horsepower ratings can be increased 40 percent.

(4) Pump thrust bearing load for deep-well turbines. To obtain pump thrust bearing load: add total hydraulic downthrust to the total weight of the pump shaft.

Example. Find the thrust bearing load for a 10-inch medium pump 250 feet deep with a 1½-inch shaft operating against a required pumping head of 300 feet.

Use values from the tables below:

Total downthrust =300 x 5+250+6=1500+1500=300 pounds.

Table of approximate hydraulic downthrust in pounds per foot of pumping head.

Pump diameter (inches)	Low capacity (pounds)	Medium capacity (pounds)	High capacity (pounds)	Pump diameter (inches)	Low capacity (pounds)	Medium capacity (pounds)	High capacity (pounds)
6	2	3	4	14	8	14	18
7	3	4	6	16	9	18	24
8	3	6	8	18		25	34
10	4	5	9	20		29	41
12	6	11	15				

(5) Weight of pump shafting in pounds per foot.

Diameter (inches)	Weight (pounds)	Diameter (inches)	Weight (pounds)	Diameter (inches)	Weight (pounds)
1	2.67	$1\frac{11}{16}$	7.6	$2\frac{3}{16}$	12.8
$1\frac{3}{16}$	3.80	$1\frac{15}{16}$	10.0	$2\frac{7}{16}$	15.9
$1\frac{1}{2}$	6.00				

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